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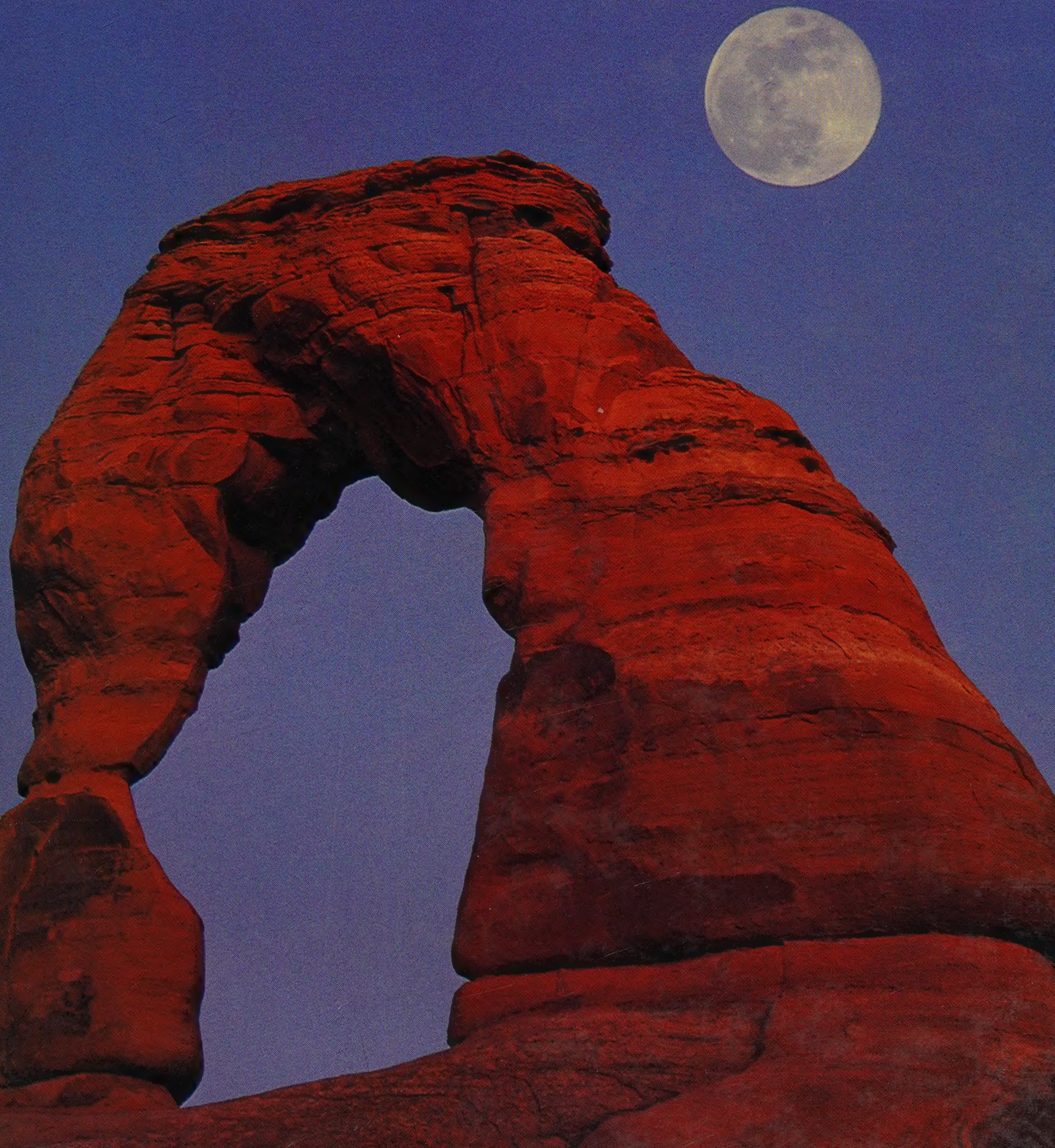
Earth Science



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Earth Science

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Our Science Heritage entries are listed by page number, chapter-section, and title.

Activities

Activities are listed by page number, chapter-section, and title.

Working Safely in the Science Classroom

In studying earth science you will be doing various activities in your classroom or in the field. There are some important things to keep in mind when working on science activities. These things have to do with **safety.** There are safe ways to handle equipment and chemicals you will be using.

The first step to take in working safely is to read carefully the description of the activity or investigation you are about to do. Look for SAFETY NOTE cautions and read them before starting the activity or investigation. Some cautions will warn you about being careful to handle hot things with oven mitts or to avoid spilling or splashing hot liquids. Other cautions will remind you to be careful not to touch edges of knives or other sharp objects, or to avoid spilling certain chemicals on your skin or inhaling chemicals.

Find out where the fire extinguisher, first aid kit, and eyewash are located. Also learn how to use these in an emergency.

Some pieces of equipment that you will be using are easy to damage if they are not used properly. Be sure to notice how your teacher handles such equipment.

A few good rules to remember when working on earth science activities and investigations are:

1. Always *ask before doing* if you are uncertain about how to do any part of an activity or investigation.
2. Always make sure that a teacher or other supervisor is present when you are working with special equipment or using new techniques.
3. Notify your teacher or supervisor *immediately* in case of injury to yourself or others, or if equipment is damaged.

Being mindful of safe procedures while working in your science classroom will help you form good working habits as a student of science.

Beginning Earth Science

Unit 1

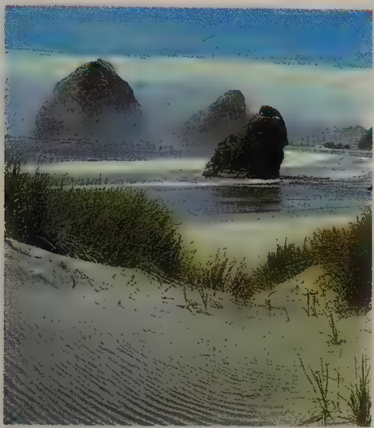
The earth can be considered as both old and new. The physical earth is billions of years old. But your understanding of and interaction with the physical earth is as new as today.

The physical earth is made up of matter—atoms, molecules, elements, and compounds that are present as liquids (the water you drink), gases (the air you breathe), and solids (the rocks and minerals in the earth beneath your feet).

Earth science involves interaction between people and the physical earth. Sometimes that interaction makes use of only a person's senses; sometimes it also makes use of the latest technology. By means of your senses, you have already learned much about the physical earth. You have a whole lifetime in which to learn more.

Chapter 1

Studying the Earth



Section 1
Learning About the Earth

You learn about the earth in the same way you learn about anything else. You begin with data obtained through your five senses. You then process that information to make inferences and to form ideas about how and why things happen.

The earth is made up of all three states of matter: solid, liquid, and gas. Different sciences study various aspects of the earth. Earth science is really a combination of sciences.

Section 2
An International System of Measuring

Objects like a door or window are made up of matter, which has certain physical properties. Among the properties of matter are size, mass, volume, and density. By using both accurate measurements and mathematical formulas, the size, mass, volume, and density of even the earth itself can be calculated.

Section 3
Mapping the Earth's Surface

The earth's surface is huge and varied. For thousands of years, people have been studying the earth they live on. During that time, representations of the earth's surface have increased in detail, in area, and in accuracy.

There are many different kinds of representations or models of the earth's surface. Each kind has advantages and disadvantages. You are probably already familiar with many of the different kinds of models of the earth's surface.

By means of a single view from space, you can learn more about the earth than earlier people could learn in an entire lifetime. From the photograph on the left, what can you tell about the earth? How could this same information be obtained if people could observe the earth only from its surface?

Learning About the Earth   Section 1

Section 1 of Chapter 1 is divided into three parts:

The scientific method

What is the earth?

What is earth science?

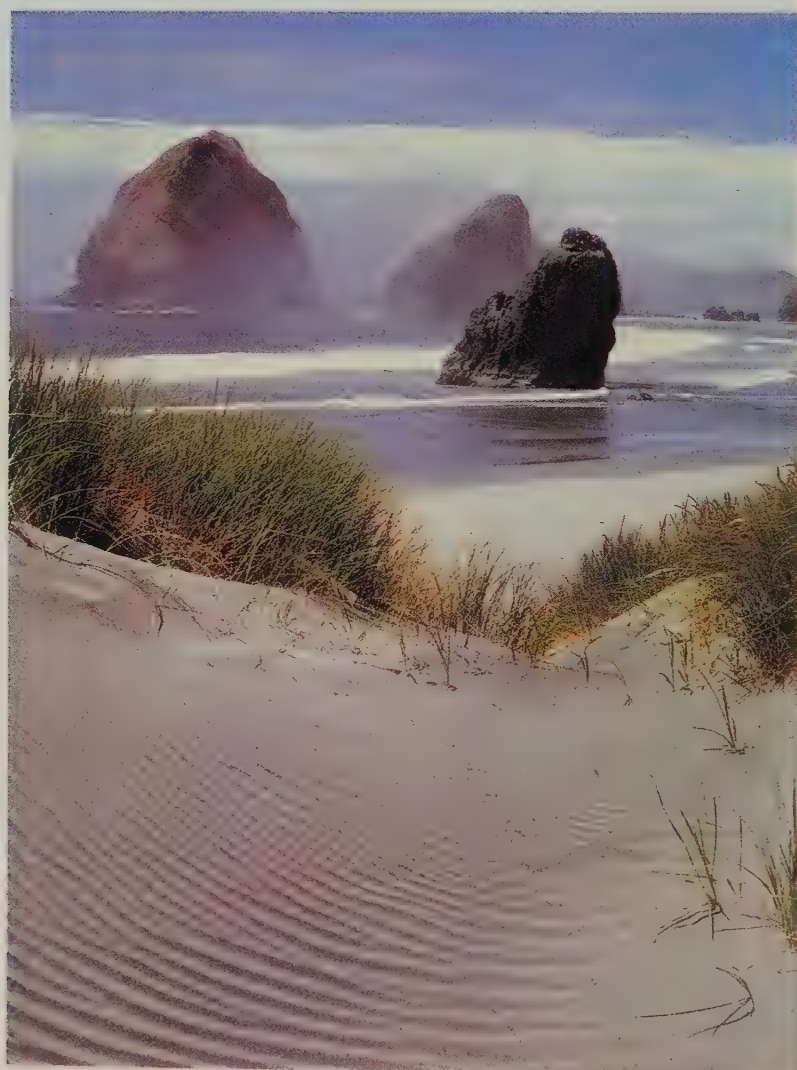


Figure 1-1. If you were walking along this beach, what could you learn through your sense of touch? through your sense of sight? through your other senses?

From earliest childhood, each of us has been learning many things about the world around us. At first, our world was very small. But because we can always learn more about the things and people around us, our world can become increasingly larger.

This earth science text will help to expand your world. You will learn what other people have discovered about the earth you live on. You will learn names for many of the earth features and processes that are within your experience. You will become more aware of ordinary, everyday earth materials.

At the beginning of this text, it might be a good idea to consider how it is that we learn anything at all. Each of us has been learning for quite some time now. So it certainly can't hurt to try and figure out what it is that we've been doing. In the process, we might even become better at it, too!

The scientific method

The *scientific method* is a way of describing "how scientists find out." Scientists have a very special way of learning what is based on experimenting. In this section you will also learn about the *processes of science,* such as observing, classifying, inferring, and hypothesizing. Through the centuries, these observations have been collected from every place that people have been able to explore or study.

How are these kinds of observations made? When you use your sense of sight, your sense of touch, your sense of hearing, or maybe even your sense of smell or taste, you are making a **direct observation.** In some instances, you will use more than one of your senses at the same time. For example, you see a wave break on the beach. At the same time, you hear its thundering noise as it hits the beach. You may even feel the spray or smell the salt in the air. These are all direct observations.

What do you use to make a direct observation?

Indirect observations. Our senses have limitations. We are unable to measure accurately the observations we make. And in some cases, we are even unable to make any observation at all

Figure 1-2. Because of telescopes like this, scientists are able to see stars and galaxies that could never be seen otherwise. Why can a telescope be called an instrument?

because the event or thing is not strong enough to be heard, seen, or felt. Sometimes the event is too slow or too fast for our senses to detect. A minor earthquake is a good example of an event that might go unnoticed by observers because of the limitations of their senses.

What are indirect observations?

How then are we able to measure and detect events or make observations if our senses have limitations? Scientists have invented **instruments** that allow us to measure according to standard units of measurement. They have also invented instruments that detect, magnify, and record information that our senses are unable to pick up. These instruments extend our senses beyond their limits. They allow us to make **indirect observations**—that is, observations that could not normally be made.

Collecting data. All sciences begin with observations, both direct and indirect. These observations are then collected and recorded. A collection of observations is known as **data.**

What is a collection of observations known as?

When scientists observe and record data, the data can be presented in a variety of forms. Data can be presented in a written description of what was observed, in chart form (as in Table 1-1), or in the form of a graph.

Collecting data is very important because it enables us to see relationships.

Classifying data. Another process involving data is by classifying it. **Classifying** is the grouping of similar events or objects, based upon observed properties or characteristics.

As you can imagine, there are very many substances on the earth. Scientists can classify these substances according to properties they possess. Different substances often have different

Average Height of Males and Females		
Age of Male or Female	Average Height of Females	Average Height of Males
8 years old	126.4 cm	127.0 cm
9 years old	132.2 cm	132.2 cm
10 years old	138.3 cm	137.5 cm
11 years old	144.8 cm	143.3 cm
12 years old	151.5 cm	149.7 cm
13 years old	157.1 cm	156.5 cm
14 years old	160.4 cm	163.1 cm
15 years old	161.8 cm	169.0 cm
16 years old	162.4 cm	173.5 cm
17 years old	163.1 cm	176.2 cm
18 years old	163.7 cm	176.8 cm
19 years old	163.8 cm	176.9 cm
20 years old	163.8 cm	176.9 cm

Table 1-1. This table presents, in chart form, average heights for males and females from 8 to 20 years old. Because people mature at their own rates, it is likely that a particular person will differ in height from the average for her or his age group.

Activity Graphing Data

Materials

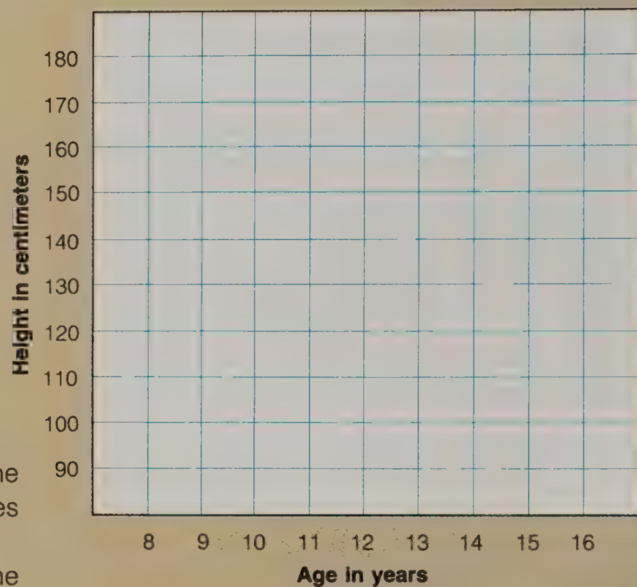
graph paper

2 pencils, each of a different color

Table 1-1 on page 7 of this text

Purpose

To display data on average height in graphic form.



What to Do

1. Look at Table 1-1. This data table gives the average heights, in centimeters, for females and males between the ages of 8 and 20.
2. List all the relationships you see between the average heights of females and their ages.
3. Do the same for males.
4. Make a list of all the relationships you see between the heights of males and females.
5. Graph the data from the data table on a graph similar to the one shown. When you connect your plotting points, do the males in one color and the females in another. Make a key or code for the colors so that your graph will be easy to read and understand.

Questions

1. Because of making your graph, can you add any more relationships to your list?
2. Were any of the relationships you listed wrong? right?
3. Between what ages do females grow fastest?
4. Between what ages do males grow fastest?
5. Which was easiest to use to answer questions 4 and 5—the data table, your lists, or your graph?
6. Not all males over 16 are 173.5 cm. Not all females over 14 are 160.4 cm. What, then, do the heights in Table 1-1 indicate?

Conclusion

Did graphing the data help you to see relationships among the data? If so, how?

Figure 1-3. Silver needs frequent polishing to keep it shiny. What causes silver to lose its shine?

physical properties and chemical properties. A **physical property** (FIZ′-uh-kul PROP′-er-tee) is a feature of the substance itself. The color and softness and shininess of silver, for example, are all physical properties of silver.

A **chemical property** (KEM′-uh-kul PROP′-er-tee) is a feature of the way that one substance reacts with another substance. Silver, for example, needs frequent polishing to keep it shiny. That is because silver readily combines with sulfur (from hydrogen sulfide in the air) to form a dark-colored substance called silver sulfide. The fact that silver tarnishes by forming silver sulfide is a chemical property of silver.

Is the tarnishing of silver a physical or a chemical property of silver?

Classifying is the scientist's way of taking many observations or events and making them more meaningful or understandable. It is a way of showing relationships among observations.

Making inferences. From observations, inferences can be made. An **inference** (IN′-fer-ins) is an interpretation of observations. Inferring is a process that suggests causes or explanations for what has been observed.

For example, the impressions shown in Figure 1-4 are shaped like a dinosaur's feet. Observing such impressions leads to the inference that a dinosaur was present before the rock layer formed. This inference may or may not be correct. More observations and information would be needed before you could be reasonably sure that the inference is true.

Activity Classifying Objects

Materials

common rocks, shells, or classroom objects

Purpose

To classify objects according to their physical properties.

What to Do

1. Have each member of your group place any three objects on the work table or desk.
2. Mix together all the objects for your group.
3. Have one person in the group sort the objects into sets. All objects in each set must share one common property. For example, all are the same color or the same shape or made of the same material.
4. Have the other members of the group guess the property that is common to all objects in each set.
5. Each person in the group should take a turn sorting the objects.

Questions

1. How many ways did your group classify all the objects?
2. Are there any properties that are common to all the objects so that all could belong to the same set? If so, what are those properties?

Conclusion

What does grouping common objects into sets tell you about their properties?

Step 2

Step 3

Figure 1-4. These fossil imprints of a dinosaur's footprints are in a rock layer that is millions of years old. What can be inferred from these footprints?

Making inferences is a key process of science and in the study of the earth. As you proceed in studying earth science, you will be presented with observations. In some cases, you will be making observations. It is important that you ask questions about those observations. Every question you ask may lead to a different set of inferences or to more questions.

Forming a hypothesis. All observations made by scientists are directed toward a better understanding of how things work, what they are like, how they began, how they change, and how they relate to one another. Basically, scientists are constantly seeking answers and explanations. Questions such as "How can we find out when an earthquake is going to occur?" give focus to scientific investigation.

There are many methods by which a scientist may work. Different problems and questions often call for a variety of techniques of looking for solutions to the questions or problems.

Frequently, a great many facts must be obtained from experimenting or observing. At other times, the facts may already be known, but the scientist must put them together so as to find the solution or answer. In either case, the scientist classifies or graphs the information that is available and then tries to reach a logical solution or conclusion. Very often, it is only an "educated guess." In the scientific method, a possible answer to a question or a possible solution to a problem, provided it is based on observations, is called a **hypothesis** (hī-POTH′-

Our Science Heritage

How Did We Find Out the Earth Is Round?

Through the ages, the earth has been thought to be flat, pear shaped, and perfectly round. What evidences led to the conclusion that the earth is round?

Back in the fourth century B.C., Aristotle offered the earth's shadow during a lunar eclipse as evidence that the earth is round. When a lunar eclipse takes place, the earth passes between the sun and the moon. This causes a shadow of the earth to appear on the surface of the moon. Aristotle noticed that the earth's shadow is curved.

Aristotle obtained another evidence of the earth's roundness by observing stars from different places. If, for example, you observe a star at an angle of 45° above the northern horizon and then move south, the star will appear to get lower in the sky. If the earth's surface were flat, then the star would always appear at 45° above the horizon.

Based on Aristotle's assumptions, Eratosthenes actually determined the circumference of the earth in the second century B.C. He did this by comparing the length of shadows in two different places at the same time.

Even much later, in Columbus's time, there was still doubt about the earth's shape. One argument used to support the earth's roundness had to do with a ship's "disappearing" over the horizon. As a ship sailed away from an observer, the ship gradually disappeared, with the lower parts disappearing before the sails and masts.

Many other evidences of the earth's shape have, of course, been offered between Aristotle's lifetime and the present day. Depending on your interest, you might research some of these other evidences on your own.

Figure 1-5. Scientists try to predict when and why events such as the eruption of Mount St. Helens take place. How do such questions affect scientific investigation?

uh-sis). Because a hypothesis is only a possible answer, scientists then perform experiments to find out whether or not it is the real answer to the question. This means that experimenting is really the testing of a hypothesis.

A hypothesis is often made when patterns can be seen in observations. Such a pattern may be developing between radon gas and earthquakes. Russian and Chinese scientists, for example, have noticed that the amount of radon gas in wells sometimes increases before earthquakes. Before a 1979 earthquake in Southern California, increased amounts of radon were observed. Such a developing pattern of observations could lead to a hypothesis like "An increase in radon gas always precedes an earthquake." Such a hypothesis, according to the scientific method, would have to be tested to see if it is true.

From hypothesis to theory. A hypothesis is not the final answer because it has not been tested. Many times, further information shows that the original hypothesis is wrong and needs to be changed. Then it is necessary to make additional observations or re-examine the old facts and experiment again.

Library research

How have scientists added to our knowledge of the earth's shape? Names to consider: Parmenides, Aristotle, Eratosthenes, Picard, Picher, Newton, Cassini, MacLaurin, Clairants, Alexander Clarke, and more recent scientists.

What happens when the observations have been made and an experiment is complete? Each time, the results are the same. Each time, the hypothesis is supported by evidence. When additional observations or data from repeated experimenting support a hypothesis, the hypothesis becomes generally accepted. Sometimes several or many hypotheses of this kind will lead to the development of a **theory** (THEE′-uh-ree). A theory is a way of explaining how or why something happened, on the basis of generally accepted hypotheses. It should be remembered that a theory is not proof. It is only based on strong evidence that the hypotheses are correct

The following sample procedure shows how a hypothesis might be set up and tested.

Problem: How can we find out when an earthquake is going to occur?

Evidence (based on observations): Isolated reports show increased amounts of radon gas before an earthquake.

Hypothesis: An increase in radon gas always precedes an earthquake.

Test: Carefully monitor radon gas concentrations in all major earthquake areas throughout the world, perhaps over a period of twenty years.

A. Note whether there is an increase of radon gas before each earthquake that occurs.
B. Note whether there is an increase in radon gas in areas where no earthquakes occur.

The data obtained during the test period can perhaps lead to a general theory about the causes of earthquakes. The theory can then be further refined by testing other hypotheses, such as "Certain events in space can cause earthquakes" or "Heavy rains on a fault plane can cause earthquakes."

Check yourself

1. What is the difference between a direct observation and an indirect observation?
2. What is the relationship between a theory and a hypothesis? Is either considered to be a proof?

What is the earth?

Many people think of the earth as a ball of rock and soil. Maybe there was a time when you did, too. The earth is more than just rock and soil. The earth is made up of all three forms of matter. Part of the earth is solid. Part of the earth is liquid. And part of the earth is gas.

Much of what you learn about the earth this year will relate to the earth's structure. The earth's structure can be thought of as having four divisions or layers. From the inside out, the earth consists of an interior, a lithosphere, a hydrosphere, and an atmosphere.

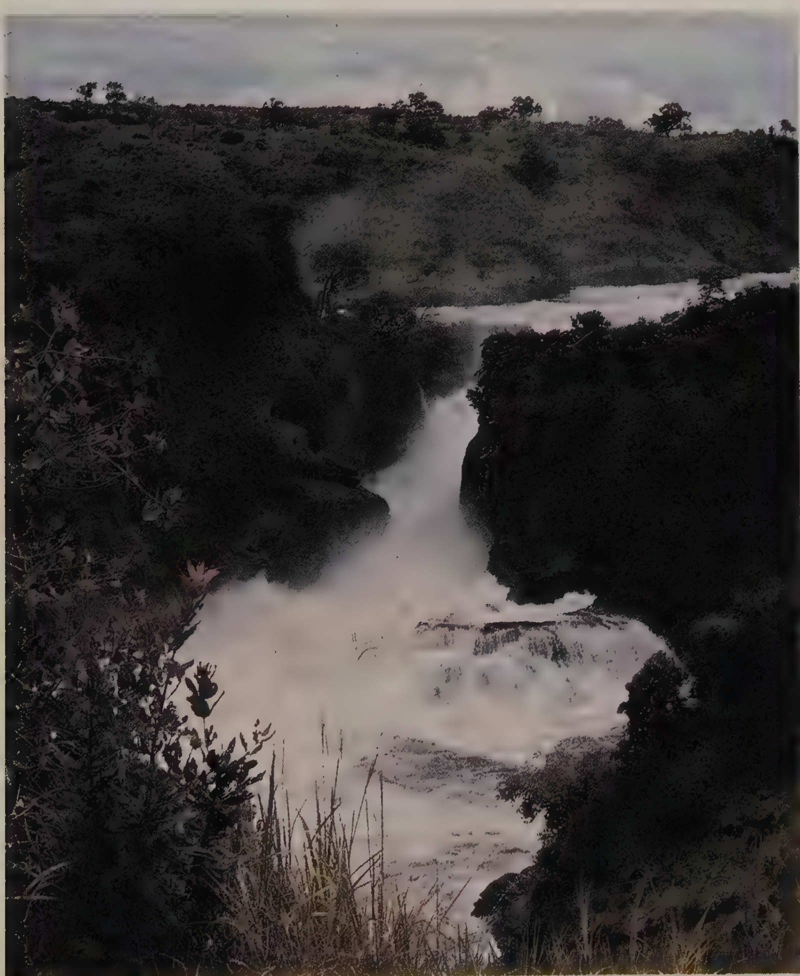


Figure 1-6. The earth is composed of all three states of matter. Where in this scene would you find a solid, a liquid, and a gas?

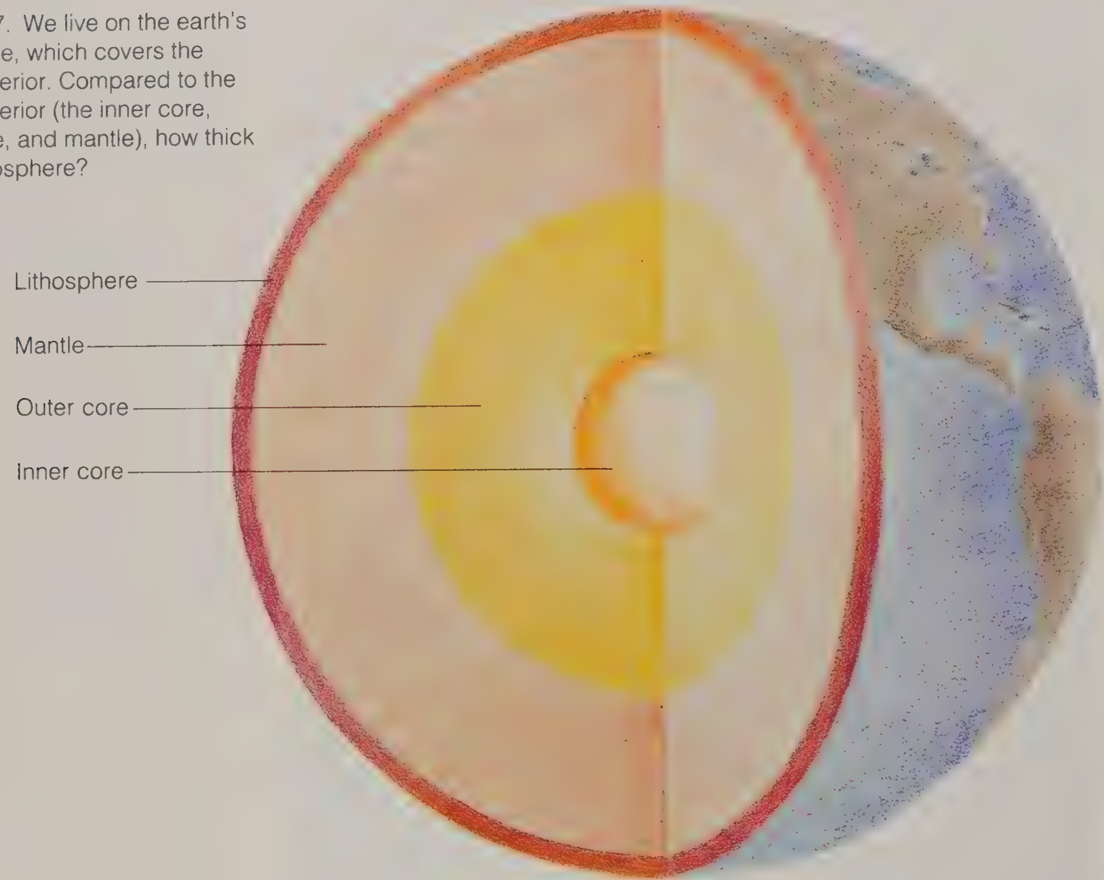


Figure 1-7. We live on the earth's lithosphere, which covers the earth's interior. Compared to the earth's interior (the inner core, outer core, and mantle), how thick is the lithosphere?

Library research

The interior of the earth is thought to have an inner core, an outer core, and a mantle. How do these regions differ from each other?

As shown in Figure 1-7, the interior of the earth is thought to have an inner core, an outer core, and a mantle. The mantle is the layer of material that extends from the earth's crust downward to the outer core. Some scientists believe that the mantle is also divided into layers, but this has not yet been proved.

Some evidence indicates that the material in the earth's interior has some properties of both solids and liquids. It is unlikely that we will really know what makes up the interior of the earth. Scientists do, however, have some theories about the earth's interior.

The earth's **lithosphere** (LITH′-uh-sfir) is the solid part of the earth that is made up of rock and soil. The word *lithosphere* comes from two Greek words that mean a stone *(lithos)* and a ball *(sphaira)*. The lithosphere is that part of the earth upon

which we live. No one knows for sure how thick the lithosphere is. One estimate puts it at between 60 and 130 km thick. Compared to the entire earth, the thickness of the lithosphere would be like the thickness of the skin of an apple.

The word *hydrosphere* (HĪ′-druh-sfir) comes from the Greek words for water *(hudor)* and ball. The earth's **hydrosphere** is composed of all the oceans and inland seas, lakes, and streams. The hydrosphere is all the water found on earth. It includes the water that is below the ground and the water that is found in the atmosphere.

The word *atmosphere* (AT′-muh-sfir) comes from the Greek words for vapor or smoke *(atmos)* and ball. The earth's **atmosphere** is the blanket of air, dust, water droplets, ice particles, etc. that completely covers the earth's lithosphere and hydrosphere. We actually live at the bottom of an ocean of air. As you go up into the atmosphere, the air thins out very quickly.

The earth's atmosphere is divided into zones or regions. Figure 1-8 shows only one of the ways that scientists divide the atmosphere. Where the atmosphere actually ends and outer space begins is still not defined.

Another of the earth's zones is called the **biosphere** (BĪ′-uh-sfir). The word *biosphere* comes from the Greek words for life *(bios)* and ball. The biosphere is not really a division of the earth's structure. Rather, the biosphere includes part of the earth's lithosphere, hydrosphere, and atmosphere. The biosphere is the region near the earth's surface where all life is found.

One of the most important ideas to remember throughout your study of earth science is that there is a constant exchange of energy and materials among the lithosphere, atmosphere, and hydrosphere. This exchange of energy and materials takes place at their boundaries or between each sphere.

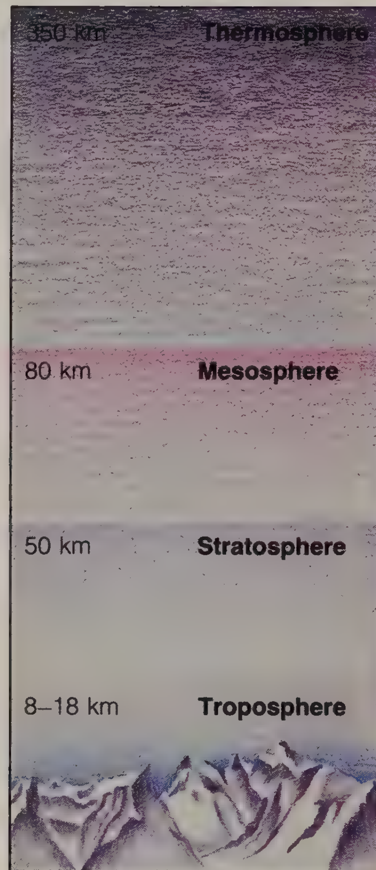


Figure 1-8. The earth's atmosphere is divided into zones or regions. What zone meets the earth's crust?

Check yourself

1. How do the earth's lithosphere, hydrosphere, and atmosphere show that the earth is made up of solid, liquid, and gas?
2. What is constantly happening at the boundaries of the different spheres?

What is earth science?

What is earth science? Each of the pictures in Figure 1-9 represents one area of science that makes up earth science. Earth science is more than a study of the surface of the earth and all its changes. Earth science is concerned with knowledge of the entire earth. Earth science is therefore concerned with the earth's lithosphere, hydrosphere, and atmosphere. As such, earth science involves many different sciences.

Is earth science a single science or does it involve many different sciences?

Earth science involves geology. **Geology** (jee-OL′-uh-jee) is the science that deals with the earth's lithosphere. Geology is concerned with the structure of the lithosphere, its composition, and what causes it to change.

Earth science involves meteorology. **Meteorology** (meet′-ee-uh-ROL′-uh-jee) is the science that deals with the earth's atmosphere. Meteorology is concerned with the composition and structure of the atmosphere. It is also concerned with the many changes that are constantly taking place in the atmosphere.

Earth science involves oceanography and hydrology. Oceanography and hydrology are sciences that deal with the earth's hydrosphere. **Oceanography** (ō′-shuh-NOG′-ruh-fee) is concerned with the earth's oceans and their boundaries. **Hydrology** (hī-DROL′-uh-jee) is concerned with the earth's entire hydrosphere, including the water below the earth's surface and the water in the earth's atmosphere.

The study of earth science really goes way beyond the earth itself. It also includes astronomy. **Astronomy** (uh-STRON′-uh-mee) is the science that deals with stars and planets. Astronomy is concerned with the size, composition, structure, and movement of stars and planets.

Does earth science also involve the sciences of chemistry, physics, and biology?

Geology, meteorology, oceanography, hydrology, and astronomy are only five of the sciences that investigate the earth. Each of those five sciences also involves the sciences of chemistry, physics, and biology. In addition, each of the major "earth sciences" is divided into very specific and specialized sciences. A geologist, for example, may be a specialist in the study of rocks. The part of geology that specializes in rocks is called **petrology** (puh-TROL′-uh-jee), from the Greek words *petros,* meaning rock, and *logos,* meaning word, thought, or branch of study.

Figure 1-9. The stars (the Pleiades cluster in the constellation Taurus), the bathyscaphe *Trieste*, the volcano (Del Fuego Volcano near the city of Antigua, Guatemala), the snow, and the tornado represent five earth sciences. Which earth science could be represented by each picture?

As you can see, then, there are really many earth sciences. In the course of this text, you will see how these various sciences blend together to form a unified presentation of our current knowledge of the earth. Also, twelve career pages, one in each chapter, will give you a better idea of what work in some of the more specialized earth sciences involves.

If, in the future, you decide to learn more about a particular aspect of the earth, you will take courses in the individual sciences that deal in greater detail with those areas of the earth that interest you most.

Check yourself

1. Why does the study of earth science involve many different sciences?
2. How does the study of astronomy differ from the study of the other four major earth sciences?

Section 1 Review Chapter 1

Check Your Vocabulary

astronomy	hypothesis
atmosphere	indirect observation
biosphere	inference
chemical property	instrument
classifying	lithosphere
data	meteorology
direct observation	oceanography
geology	petrology
hydrology	physical property
hydrosphere	theory

Match each term above with the numbered phrase that best describes it.

1. The science concerned with the earth's entire hydrosphere
2. The blanket of air, dust, water droplets, ice particles, etc. that completely covers the earth's lithosphere and hydrosphere
3. A feature of a substance in itself
4. An interpretation of observations
5. The region where all life is found
6. The solid part of the earth
7. Based on strong evidence that several generally accepted hypotheses are correct
8. Information received by one or more of the senses
9. Grouping similar objects or events
10. Used to extend our senses when making observations
11. The science concerned with the oceans
12. A feature of the way one substance reacts with another substance
13. An observation that requires the use of an instrument
14. The science concerned with the earth's lithosphere
15. Possible answer to a problem, based on observations
16. The science concerned with the earth's atmosphere
17. The part of geology that specializes in rocks
18. The entire liquid or water part of the earth
19. The science concerned with stars and planets
20. A collection of observations

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. All sciences begin with ?.
   a) theories c) classifying
   b) observations d) hypotheses
2. Among the lithosphere, atmosphere, and hydrosphere, there is ?.
   a) an increase in radon gas
   b) a constant exchange of energy and materials
   c) a layer that has some properties of both solids and liquids
   d) a ball of rock and soil

Check Your Understanding

1. Explain how an indirect observation can be more accurate than a direct observation.
2. Explain the difference between an observation and an interpretation.
3. Explain the difference between a chemical property and a physical property.
4. Explain why the biosphere includes part of the earth's lithosphere, hydrosphere, and atmosphere.
5. Explain why the name of this book could be *Earth Sciences* rather than *Earth Science*.

Section 2 of Chapter 1 is divided into six parts:

The International System of Units (SI)

Measuring length

Measuring mass

Determining volume

Determining density

Measuring the earth

Figure 1-10. In order to make a door that fits properly, it is necessary to have accurate measurements. If you were to make a door and frame like this one, what measurements would you need? What instruments could you use to make the measurements?

Simple observation in science is fine for providing certain kinds of information. But for other kinds of information, some kind of instrument is also needed.

Let's say your friends want a bulletin board for the hallway in their apartment. They want the biggest bulletin board that will fit on the wall between the door to the kitchen and the door of the hall closet. What can you do if you want to get them that bulletin board?

You could go to the store and look at the different size bulletin boards they have. You could then buy the one that looks like it might fit. But you'd be taking a chance. You could easily buy one that won't fit the way your friends want it to.

How can you be sure the one you buy will fit? You can measure the space on the wall. You can then tell the person at the store how big a space you want to fill. The person at the store will then know exactly what size bulletin board to give you to best fill the space.

The International System of Units (SI)

It is helpful to be able to measure the length of a wall, the width of a doorway, or the height of a shelf. But people have also wondered about the measurements of larger objects, too. How high, for instance, is a certain tree or a certain mountain? How big, even, is the earth itself? To find the answers to questions like these, a very good system of measurement is needed.

What makes a system of measurement good? First of all, a good system of measurement must be based on standards of measure that never change. Secondly, the basic units of measure should be easy to work with. And thirdly, the system of measurement needs to be accepted and used by many people all over the world.

What do the initials SI stand for?

A present-day system of measurement that meets the requirements for a good system is called the International System of Units. Its initials are **SI,** after its name in French, *le Système International d'Unités.*

The International System of Units, which was agreed upon in 1961, is based on a form of the metric system. The metric system traces back to France in 1790. A committee was formed

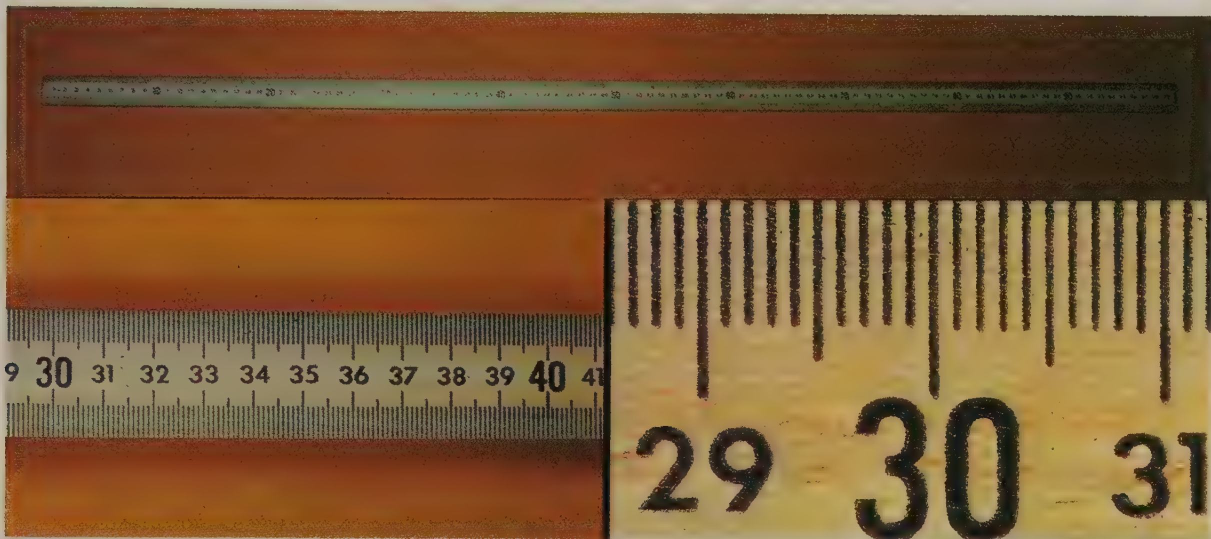


Figure 1-11. A meter stick is divided into 100 cm. Into how many smaller units is each centimeter divided?

to decide on a single system of measurement that could be used throughout all of France. For ease of use, the new system was to be based on multiples of ten. Also, there was to be an interrelationship among the basic units for length and volume and mass.

For the new measuring system, a standard for measuring length was needed. It was decided that the size of the earth itself would somehow be used. To arrive at a standard for measuring length, the distance between the North Pole and the equator was divided by ten million. The resulting length was called a **meter,** from the Greek word *metron,* which means a measure. This length was then marked on a metal bar that for a long time served as the standard to be used in making other meter-length measures. Later, it was found that the length of the meter was not exactly one ten-millionth of the distance between the North Pole and the equator. But the measure was retained as a standard unit.

The metric system developed by the French was not immediately accepted by other people. It took many years before it came to be widely used. By the 1950s, many varieties of metric measures were in use. There was clearly a need, on a worldwide scale, for the International System of Units.

The International System of Units uses seven base units, shown in Table 1-2. As a student, you will probably have the

Base Units of the International System of Units (SI)		
Name	Property Measured	Symbol
meter	length	m
kilogram	mass	kg
second	time	s
ampere	electric current	A
kelvin	temperature	K
candela	luminous intensity (brightness)	cd
mole	number of particles of a substance	mol

Prefixes Used with SI Base Units		
Prefix	Symbol	Value Numbers
mega	M	1 000 000 times the base unit
kilo	k	1 000 times the base unit
hecto	h	100 times the base unit
deka	da	10 times the base unit
deci	d	0.1 times (1/10 of) the base unit
centi	c	0.01 times (1/100 of) the base unit
milli	m	0.001 times (1/1000 of) the base unit
micro	μ	0.000001 times (1/1 000 000 of) the base unit

Table 1-2. The International System of Units (left) uses seven base units. Which two will you probably have most need of?

Table 1-3. The SI system (right) uses prefixes to indicate quantity. The prefixes make it easier and faster to multiply, divide, and make conversions.

most need for the units of length and mass. Some of the other base units are used mainly in specialized sciences. The symbols for ampere and kelvin are capital letters because those base units are named after people who lived in the past.

Along with the base units, the SI system uses prefixes to indicate quantities. The prefixes, given in Table 1-3, make the SI system easier and faster to work with when it comes to multiplying and dividing. It also makes it easier to convert from one unit to another.

The prefixes most commonly used by students are kilo (k), centi (c), and milli (m). If you look at a meter stick, you will see that 1 m = 100 cm = 1000 mm. A centimeter (1 cm) is therefore one one-hundredth of a meter. A millimeter (1 mm) is one one-thousandth of a meter.

Note that one of the base units, the kilogram, already has a prefix. The kilogram actually is 1000 (kilo) grams. But the gram was not chosen as the base unit because of its very small amount.

Check yourself

1. What makes a system of measurement good?
2. What are the two most common base units used by students?
3. Why are prefixes used with base units?
4. When the metric system was first being set up at the end of the eighteenth century, what distance on the earth was used as the standard for a meter length?

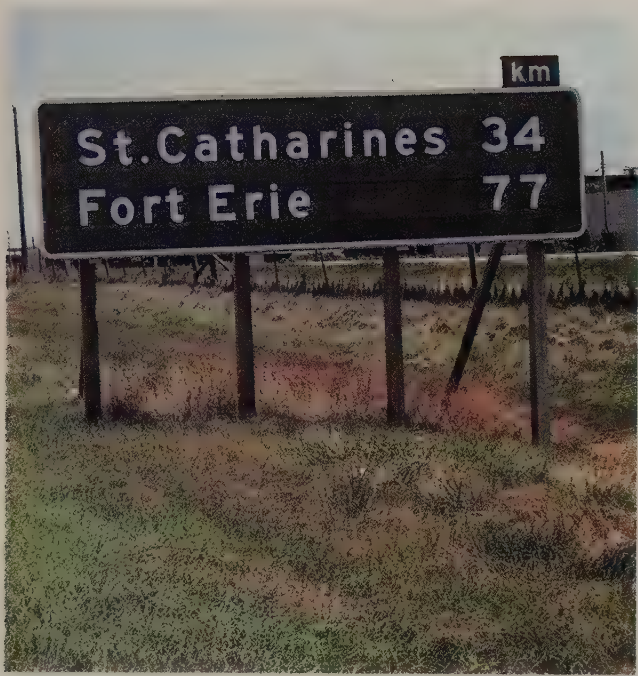


Figure 1-12. How do the units of distance on these road signs differ?

Measuring length

Marks on a metal bar no longer provide the standard for a meter length. Even under very carefully controlled conditions, the size of the metal bar was found to be not perfectly constant. The standard now used is not even a physical object. The standard is based on the wavelength of a special kind of light. However, there is no need for you to worry about this. For practical purposes, an accurate ruler or measuring tape is the only standard you will need for measuring length.

Today, many of the road signs in the United States give distances in kilometers as well as miles. The United States has been slow to adopt the metric system, however. In Canada and most other countries, the distances are given only in kilometers.

One nice thing about the metric system is that you don't have to worry about remembering the answers to questions like these:

How many inches are in a foot?

How many feet are in a yard?

Library research

The United States is one of the last countries to adopt the metric system. Prepare a report on the Metric Conversion Act of 1975. How much progress in using metric has occurred in the United States since 1975?

How many feet are in a mile?

How many yards are in a mile?

Which is longer—316 yards or 950 feet?

With the metric system, the prefix tells you how many. In the case of kilometers, the prefix *kilo* tells you it's one thousand times the base unit, meter(s). And to go from kilometers to meters to centimeters is easy, too. All you have to do is move the decimal point. For example, 95 km = 95 × 1000 m = 95.000. m.

Even though a new measuring system may have clear advantages, it is not easy to get people to change over from their old system. A measuring system is so much a part of a person's way of thinking that to suddenly have to start thinking in different units is very difficult.

Check yourself

1. How many cm are in 1 m? What does the prefix *centi* mean?
2. How many mm are in 1 m? What does the prefix *milli* mean?

Measuring mass

As indicated in Table 1-2, the base unit for measuring mass is the kilogram. The standard for the kilogram is a special metal cylinder that is kept by the International Bureau of Weights and Measures in Paris, France. An exact copy of that cylinder is kept as a standard in the United States. The kilogram is the only base unit whose standard is still a physical object.

Which base unit is the only one whose standard is still a physical object?

In everyday speech, the term *weight* is used to mean mass. But strictly speaking, weight and mass are not the same thing. The following example illustrates the difference between mass and weight.

Weight is the pull of gravity on nearby objects. On the earth, weight is the pull of the earth's gravity on objects near or on the surface of the earth. On the moon, weight is the pull of the moon's gravity on objects near the surface of the moon. Weight can vary depending on gravity. **Mass** is the amount of material in something. It is the same everywhere.

The 1-kg mass in Figure 1-13 is hanging from the same spring scale on the earth and on the moon. But the 1-kg mass weighs less (only 1/6 as much) on the moon. This is because the moon's gravity is not as strong as the earth's. The moon's gravity does not pull as strongly on the mass and spring.

Does a 1-kg mass weigh the same on the earth and on the moon?

But the 1-kg mass has not changed. It has just as much material, or mass, in it on the moon as it has on the earth.

Now suppose we take a lump of clay and put it on a beam balance with the 1-kg mass, as shown in Figure 1-14. On the earth, the clay and the 1-kg mass balance, so the mass of the clay on the earth is 1 kg. What would the mass of the clay be on the moon?

When we take the same clay, 1-kg mass, and beam balance to the moon and set it up, we find that the clay and the 1-kg

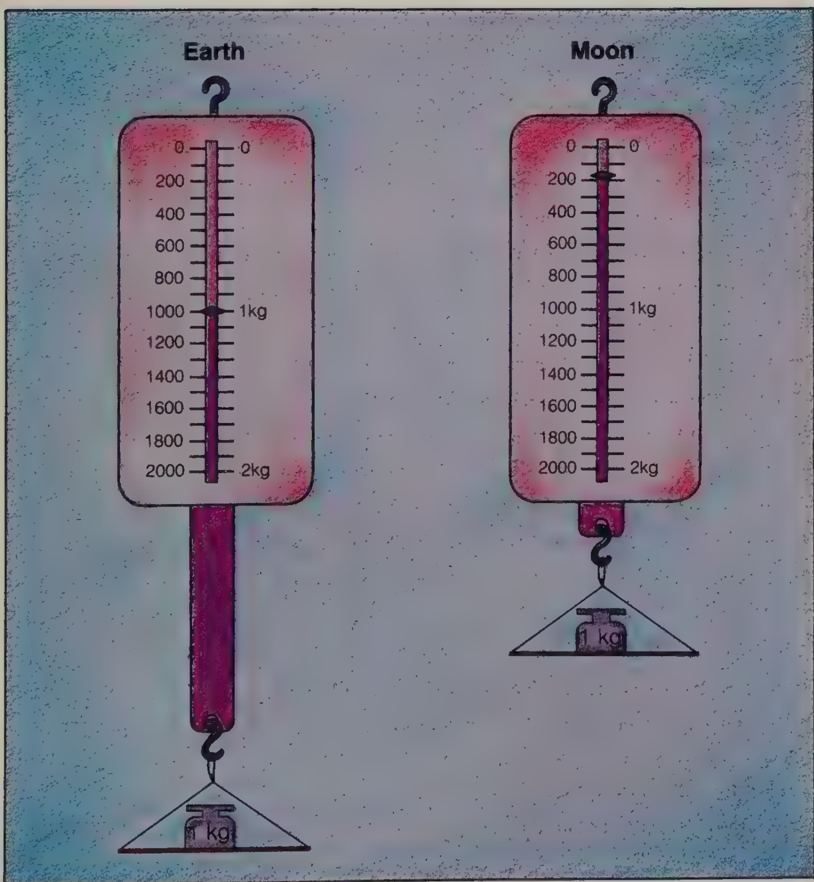


Figure 1-13. A spring scale is used to measure weight. Why does a 1-kg mass weigh only 1/6 as much on the moon as it does on the earth?

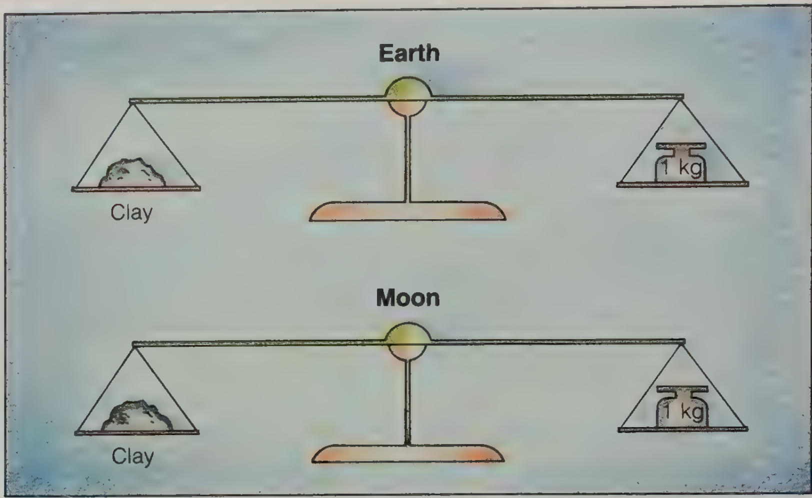


Figure 1-14. A beam balance is used to measure mass. Does a 1-kg mass balance the same mass of clay on the moon as it does on the earth?

How can you tell that the mass of the 1-kg mass in Figure 1-14 is the same on the earth as on the moon?

mass balance each other there, too. The mass of the clay has not changed. It balances the same 1-kg mass on both the earth and the moon. We can see from this little experiment that weight is really a measure of the pull of gravity and that weight changes as the pull of gravity changes.

Check yourself

1. Why would a person weighing 60 kg on the earth weigh 10 kg on the moon?
2. What would be the mass of an object if it were balanced by a 3-kg mass?

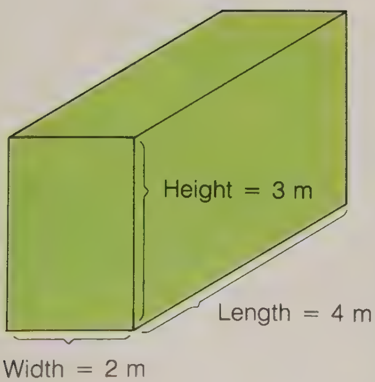
Determining volume

It is possible to combine two or more base units. You then have a **derived unit** such as volume. **Volume** is the amount of space that an object takes up.

Figure 1-15 shows how the volume of a solid is derived by multiplying the length times the width times the height of a solid object. The volume of a solid is most frequently expressed in cubic centimeters (cm^3) or cubic meters (m^3).

It is also possible to determine the volume of the inside of a container that holds a liquid or gas. The unit of measure used in this case is called the liter (L), which is often used for liquid measurement.

A graduated cylinder like the one shown in Figure 1-16 is often used for such measurements. A set of marks on the side of the cylinder is used to measure the volume of the liquid that



Volume = length × width × height
Volume = 4 m × 2 m × 3 m
Volume = 24 m^3 or 24 cubic m

Figure 1-15. Volume is a derived unit. How is a derived unit different from a base unit?

is in the cylinder. To measure the volume of a liquid, you merely pour it into the graduated cylinder and take the reading that corresponds with the level of the liquid. The volume of a small amount of liquid is most frequently expressed in milliliters (mL).

Some solid objects cannot be measured with a ruler. But there is an easy way to find the volume of objects like these, too. It is called the water displacement method. The object is submerged in water, causing the water level to rise. The new level of the water is equal to the volume of the water plus the volume of the object. To calculate the volume of the object, you subtract the original volume of the water level reading from the water level reading with the object submerged in the water. 1 mL (liquid volume) equals 1 cm^3 (solid volume). Therefore, if a solid displaces 30 mL of water, it has a volume of 30 cm^3.

What method can you use to find the volume of an object that cannot be measured with a ruler?

Check yourself

1. How would you find the volume of a block of wood?
2. How would you find the volume of an irregular-shaped object such as a rock?

Figure 1-16. This graduated cylinder is an instrument that measures liquid volume in milliliters (mL). It can also be used to measure the volume of some solids. What is the volume of the stone that was lowered into the water in the cylinder on the right?

Activity Using Base Units to Measure

Materials

meter stick or metric rule
graduated cylinder
balance
water
coins
wooden blocks

Purpose

To measure length, volume, and mass, using base units in the SI system.

What to Do

A. Length
On a sheet of paper, construct three lines equal to these lengths: 20 cm, 4.5 cm, and 24 mm.

Question

Have another student measure your lines. Did you make them the right length?

B. Volume of a Solid
Find the volume of a wooden block by measuring the length, width, and height. Multiply these three measurements to find the volume.

Question

What is the volume of the solid in cm^3?

C. Volume of a Liquid
Examine the graduated cylinder with water in it.

Question

What is the volume in mL?

D. Mass
Using a balance, find the mass of each of several coins.

Questions

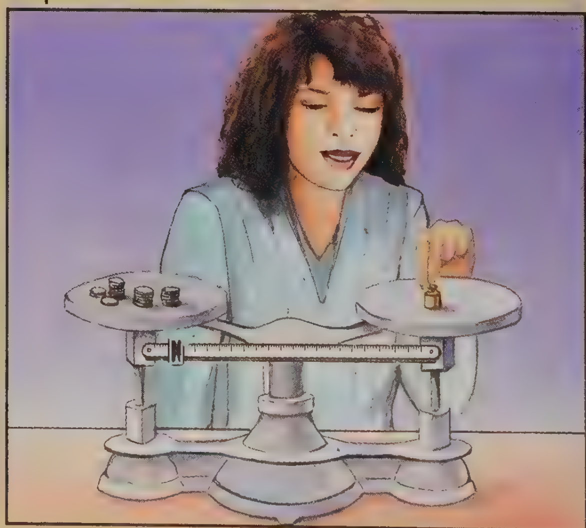
1. How do your findings compare with those of a classmate?
2. How could you find the mass and volume of the paper you are writing on? The paper does not have enough mass to get a reading on the balance. It does not have enough thickness to measure with a ruler.

Conclusion

How do instruments affect observation?

Step C

Step D



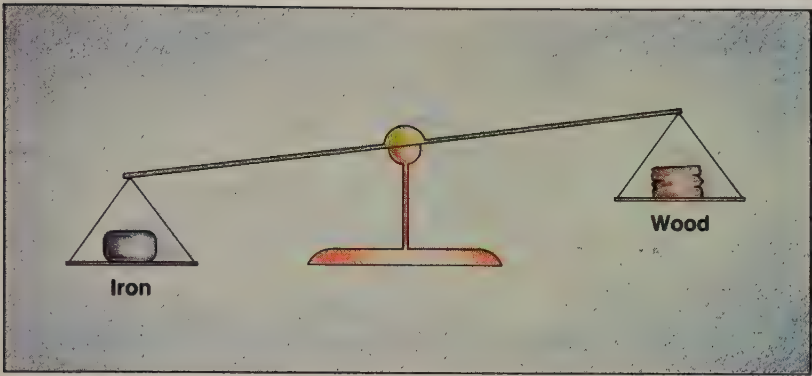


Figure 1-17. The same volume of iron and wood do not balance each other. What is the reason for this?

Determining density

You know that certain materials are more "dense" than other materials. You would expect a certain volume of iron, for example, to weigh more than the same volume of wood. Iron is more dense than wood.

Density is the mass of 1 cm^3 of a material. To find the density of a material, you must find its mass and its volume. You then divide its mass by its volume.

To find the density of a material, what two measurements must you find first?

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Let's say, for example, that a certain block of copper has a volume of 8 cm^3. Its mass is 72 g. The density of copper would be expressed as the mass (in grams) of 1 cm^3 of copper.

$$\text{density of copper} = \frac{72\text{ g}}{8\text{ cm}^3} = 9\text{ g/cm}^3$$

In your study of earth science, you will see how differing densities of air masses cause winds. You will also see how differing densities of water cause ocean currents.

Check yourself

1. How could you determine the density of an object?
2. Suppose a metal bar had a mass of 24 g and a volume of 3 cm^3. What would be its density? Show your work.

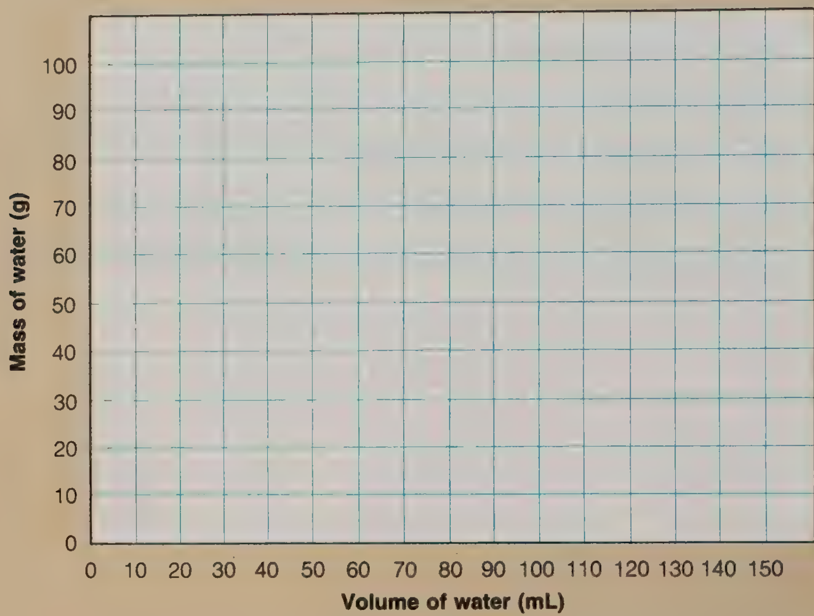
Activity Graphing the Density of Water

Materials

balance
graduated cylinder
water
eyedropper
graph paper

Purpose

To find the mass of four different amounts of water.



What to Do

1. Find the mass of an empty graduated cylinder. Record the measurement.
2. With your teacher, construct a data table for each mass and volume of water.
3. Put 10 mL of water into the graduated cylinder. (By using an eyedropper, you can make the measurement more accurate.)
4. Find the combined mass of the graduated cylinder and the water in it.
5. Calculate the mass of only the 10 mL of water and record your finding.
6. Empty the graduated cylinder and repeat the procedure, using 20 mL, 30 mL, and 50 mL of water. Each time, find the mass of only the water.
7. After you have found the mass and volume of each amount, plot the data on a piece of graph paper. Following the samples on this page, indicate volume of water (in mL) across the bottom of the graph. Indicate mass of water (in g) up the left side of your graph.
8. On your graph, plot the mass for each amount of water. Then calculate the density for each volume of water. Use the formula

$$\text{density} = \frac{\text{mass in g}}{\text{volume in mL}}$$

for 10 mL, 20mL, 30 mL, and 50 mL of water.

Questions

1. Are your calculations of density the same for all four volumes?
2. The unit of density for the water is g/mL. How does this compare with the unit of density used for the copper bar? Why should there be a difference in the units?

Conclusion

Do different volumes of water have different densities? What can the graph tell you about the relationship between volume of water and density of water?

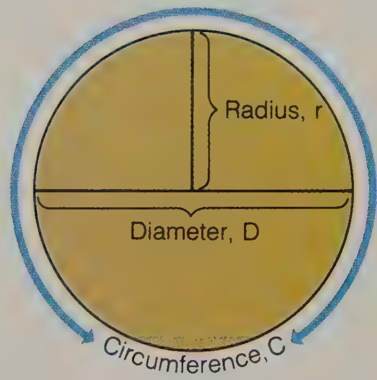
Measuring the earth

Circumference is the distance around a circular object. Scientists know the circumference of the earth. They obtained this information from very accurate measurements of the pull of gravity, from space flights, and from photographs taken from space. The earth's circumference, if measured around the equator, is 40 076 km. The earth's circumference, if measured through the poles, is 40 008 km.

Because of the difference in the two circumferences, you can see that the earth is not perfectly round. There is a slight flattening at the poles. And there is a slight bulge at the equator. But these slight differences in the shape of the earth are very small compared to the overall size of the earth. They are so small that if you were asked to draw a picture of the earth, you would draw a circle. If you were asked to make a model of the earth, you would make a round globe.

Once the earth's circumference is known, its radius, its diameter, its surface area, and its volume can be calculated. Scientists used mathematical formulas to obtain these measurements because it is obviously impossible to measure them directly. Figure 1-18 shows the formulas that can be used to obtain various earth measurements.

Scientists have even calculated the density of the earth. As shown in Figure 1-18, scientists could calculate the volume of the earth once they knew its circumference. But how could they obtain its mass? They certainly couldn't put the earth on a balance. They were able to use the earth's force of gravity to obtain its mass. Scientists were able to calculate the force with which the earth attracts objects to its surface. Using this information, they calculated the density of the earth to be 5.5 g/cm^3.



Radius, $r = \frac{C}{2\pi}$

Diameter, $D = 2r$

Circumference, $C = \pi D$

Surface area, $A = 4\pi r^2$

Volume, $V = \frac{4}{3}\pi r^3$

Figure 1-18. Once the earth's circumference is known, other earth measurements can be calculated by using mathematical formulas. What is the relationship between diameter and radius?

What density did scientists calculate for the entire earth?

Check yourself

1. How have scientists obtained the information needed to calculate the earth's circumference?
2. Once the earth's circumference is known, what four other earth measurements can be calculated?
3. How were scientists able to calculate the earth's density?

Section 2 Review Chapter 1

Check Your Vocabulary

circumference	meter
density	SI
derived unit	volume
mass	weight

Match each term above with the numbered phrase that best describes it.

1. A standard unit of length originally based on the distance between the North Pole and the equator
2. The pull of gravity on an object
3. The distance around a circle or ball
4. Initials for International System of Units
5. The mass of 1 cm^3 of a material
6. The amount of material in something
7. The amount of space that an object takes up
8. A unit of measure obtained from two or more base units

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. _?_ is the base unit used for measuring length.
   a) Kilogram c) Centimeter
   b) Meter d) Liter
2. The prefix kilo (k) means _?_.
   a) one hundred
   b) one one-thousandth
   c) ten
   d) one thousand
3. The _?_ is the only unit of measure that contains a prefix and that is a base unit.
   a) centimeter c) gram
   b) kilogram d) millimeter
4. Measuring the amount of water displaced by a submerged object is a way of determining the _?_ of the object.
   a) height c) volume
   b) density d) weight
5. If a solid displaces 30 mL of water, it has a volume of _?_
   a) 60 cm^3 c) 30 cm^2
   b) 30 cm^3 d) 30 cm

Check Your Understanding

1. Explain why the metric system is a good system of measurement.
2. Describe the difference between mass and weight.
3. The mass of a rock is 36 g. The volume of the rock is 9 cm^3. Explain how to find the density of the rock? What is the density of the rock?
4. Explain why a model of the earth would be round even though the earth is not perfectly round.
5. Using 3.1 as π, find the circumference, radius, and surface area of a ball with a diameter of 10 cm. Show your work.

Mapping the Earth's Surface   Section 3

Section 3 of Chapter 1 is divided into seven parts:

Latitude and longitude

Map projections

Colors and symbols on maps

North, on a map

A scale of distances

Topographic maps

Different ways to find north

Figure 1-19. The surface of the earth is huge and varied. Over the centuries, models of the earth's surface have been developed with increasing accuracy and detail. If you were making a model of this section of the earth's surface, what features would you feel you had to include?

What is a globe?

A **globe** is a physical model of the earth. Because the earth is almost a perfect sphere, globes are the only true representations of the earth. But a globe may be only the size of a basketball. The surface area of the earth, on the other hand, covers almost 513 000 000 km^2. Detail and accuracy of particular places and features are impossible to provide on such a globe. For close-up representations of sections of the earth, there are maps that show this detail and accuracy.

Latitude and longitude

"Meet me on Main Street and we can walk to the movies together." Probably the first thought that comes to your mind is "whereabouts on Main Street?" If the other person had said, "Meet me at the corner of Main Street and Second Avenue, in front of the drug store," you would have known exactly where to go.

This method of giving locations works well as long as there are streets that can be identified. But what happens out in the country or in a strange land, or even out on the ocean? How are people able to locate places on earth?

The place where Main Street and Second Avenue cross is called an intersection. Intersections called coordinates can also be plotted for any point on the earth's surface. A system of reference points, or coordinates, can be established by drawing two sets of lines or rings around the earth.

Figure 1-20. Intersections are useful for describing locations. How would you describe the location of the A on the map?

One set of rings runs east-west around the earth, parallel to the equator. These east-west lines or rings are called **parallels.** Parallels enable a person to measure the latitude of any point on earth. **Latitude** is the distance any point is north or south of the equator.

Another set of lines runs north-south. They cross the equator at right angles, and they meet at the North and South Poles. These north-south lines are called **meridians.** Meridians enable a person to measure the longitude of any point on earth. **Longitude** is the distance that any point is east or west of the prime meridian.

Latitude and longitude were introduced by a Greek philosopher, Ptolemy, about 150 A.D. The present system of numbering the parallels and meridians, however, goes back only to 1884. At that time, a group of astronomers was meeting in Washington to discuss how to calculate time around the world. They decided to use Greenwich, England, the site of an important observatory, as the starting point for calculating time. In doing so, they also agreed that an imaginary line passing through Greenwich, England, would be called the **prime meridian.**

Parallels are numbered in degrees north and south of the equator. As shown in Figure 1-22, the **equator,** which is the beginning line for latitude, has a latitude of 0°. Beginning at

Figure 1-21. This photograph shows the original Royal Greenwich Observatory at Greenwich, England. What does that observatory have to do with our being able to describe locations in terms of latitude and longitude?

When and by whom were latitude and longitude first used?

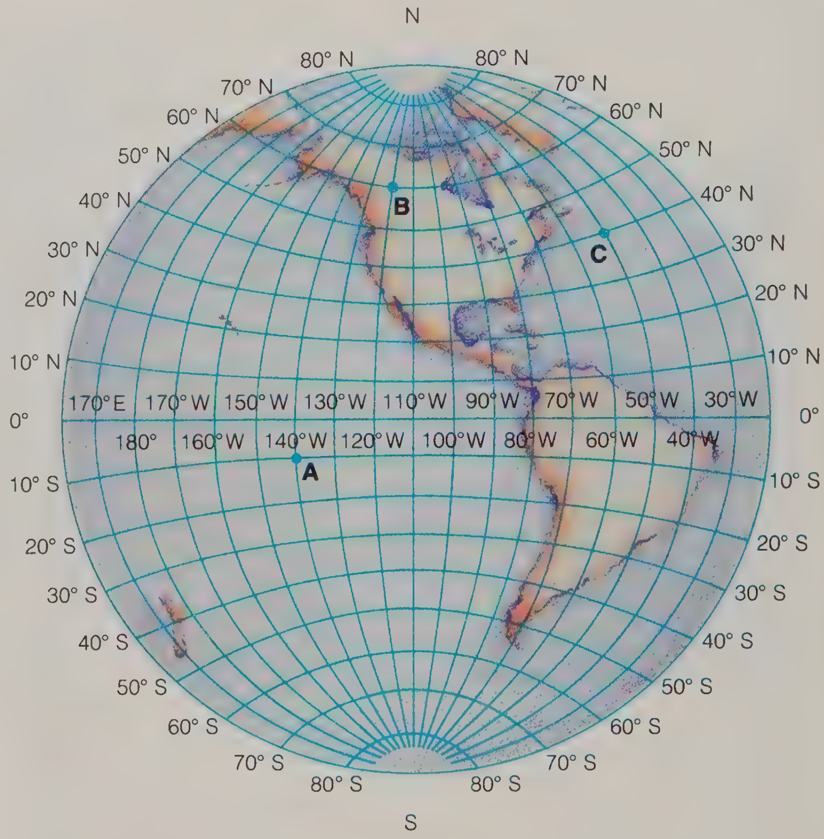


Figure 1-22. Any location on the earth can be described in terms of latitude north or south of the equator and longitude east or west of the prime meridian. How can you identify points A, B, and C, using latitude and longitude?

How are meridians numbered?

the equator, the parallels of latitude are numbered from 0° (the equator) to 90° North (the North Pole) and from 0° (the equator) to 90° South (the South Pole). Note that it is impossible to have a latitude greater than 90°. Note also that it is necessary to indicate North or South latitude because latitude can have the same value either side of the equator.

Meridians are numbered in degrees east and west of the prime meridian, which passes through Greenwich, England. Starting at the prime meridian, each meridian is numbered from 0° to 180° East or from 0° to 180° West. No place on earth can have a longitude greater than 180°. Because longitude can have the same value either side of the prime meridian, the direction east or west must also be indicated.

The length of just 1° of latitude at the equator is about 111 km. The length of 1° of longitude at the equator is about 111 km. Therefore, the area contained within just 1° latitude by 1° longitude at the equator (about 111 km × 111 km) covers more than 12 000 km^2. If you were lost and a plane was looking for you, your chances of being found in so large an area are

not very good. For greater accuracy, degrees can be divided into sixty smaller units called minutes. And each minute can be divided into sixty units called seconds. This is similar to the meter being divided into centimeters and centimeters being divided into millimeters.

As shown in Figure 1-22, the meridians get closer and closer as you travel north or south from the equator. At the equator, 1° of longitude is equal to about 111 km. At 40° North or South latitude, however, 1° of longitude is equal to about only 79 km.

On the other hand, each parallel is an equal distance from every other parallel. One degree of latitude is therefore equal to about 111 km at the equator and at every other place on earth. The only exception to equal distance between parallels is at the poles. This slight difference is because of the flattening of the earth's surface at the polar regions.

Library research

Find the exact location in longitude and latitude of your school.

Check yourself

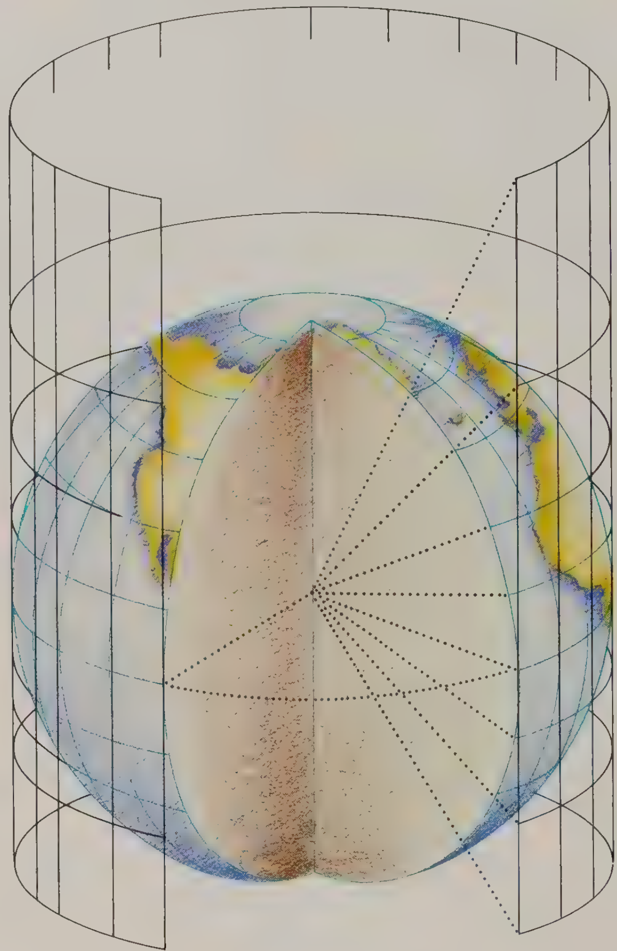
1. Explain how latitude and longitude provide a system of coordinates for locating places on the earth's surface.
2. What is the starting point for measuring latitude? for measuring longitude?
3. Why is it necessary to use N and S when describing latitude and E and W when describing longitude?

Map projections

Maps are representations, on a flat surface, of all or part of the earth's surface. It is impossible to put the earth's curved surface on a flat surface accurately. Therefore, map projections have been devised. A **map projection** is an attempt to represent the earth's curved surface on a flat surface.

Many different ways can be used to try to project curved parallels and meridians onto a flat surface. But no way is perfect. Some map projections are very accurate for the sizes of the continents. Other map projections are accurate for the shapes of the continents. Still other map projections are accurate for distances and directions on the earth's surface.

Figure 1-23. On a globe, each parallel is an equal distance from every other parallel. On the map projection to the right, what happens to distances between parallels north or south of the equator when lines of latitude and longitude are projected onto a cylinder?



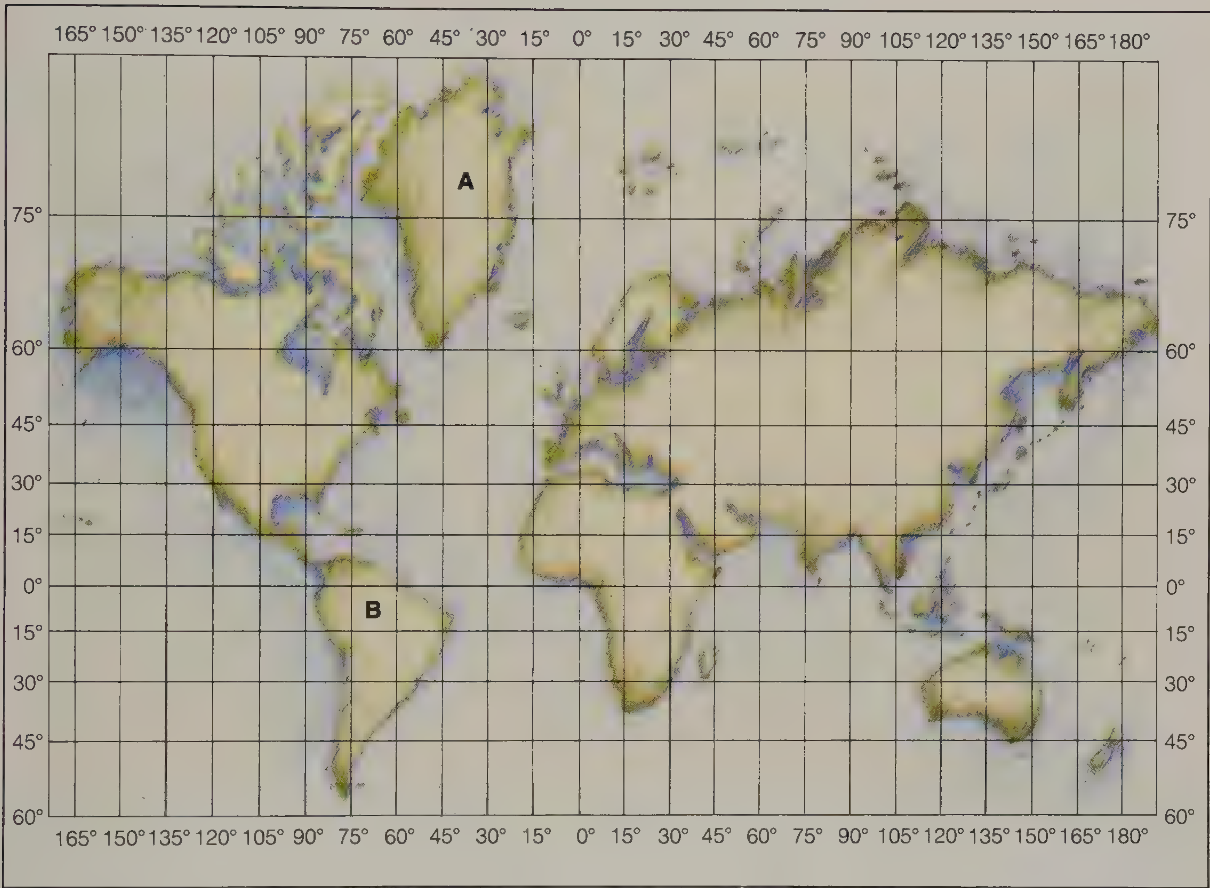
Library research

Planes flying from San Francisco to Japan or from New York to London do not fly due west or due east. They follow a "great circle." Find out why.

What is the most commonly used map projection for mapping small sections of the earth?

Figure 1-24 shows a Mercator projection of the earth. In that projection, note the size of Greenland (labeled A on the map). It appears larger than South America (labeled B on the map). In reality, however, South America is almost three times longer, in a north-south direction, than Greenland. The Mercator projection is accurate for direction. But the Mercator projection is inaccurate for size and distance, and at the higher latitudes the distortion becomes even greater. Even with this distortion, however, the continents can be recognized by their general shapes.

The most commonly used projection for mapping small sections of the earth is the polyconic projection. The polyconic



projection is most nearly accurate for distance, direction, size, and shape.

Figure 1-24. On this Mercator projection of the earth, how accurate is the size of Greenland (labeled A on the map)?

Check yourself

1. How is a map similar to a globe? How is it different?
2. In a Mercator projection, how are distances affected at the higher latitudes?

Colors and symbols on maps

Symbols on maps make it easier to identify features. These symbols are often in different colors. Figure 1-25 lists the basic colors used on maps. It also lists what the colors represent and gives some examples.

Activity Locating Places on the Earth

Materials

globe or world map
piece of string

Purpose

To locate some places on the earth using latitude and longitude.

What to Do

Using the piece of string, if necessary, and a map or globe, answer questions 1-5.

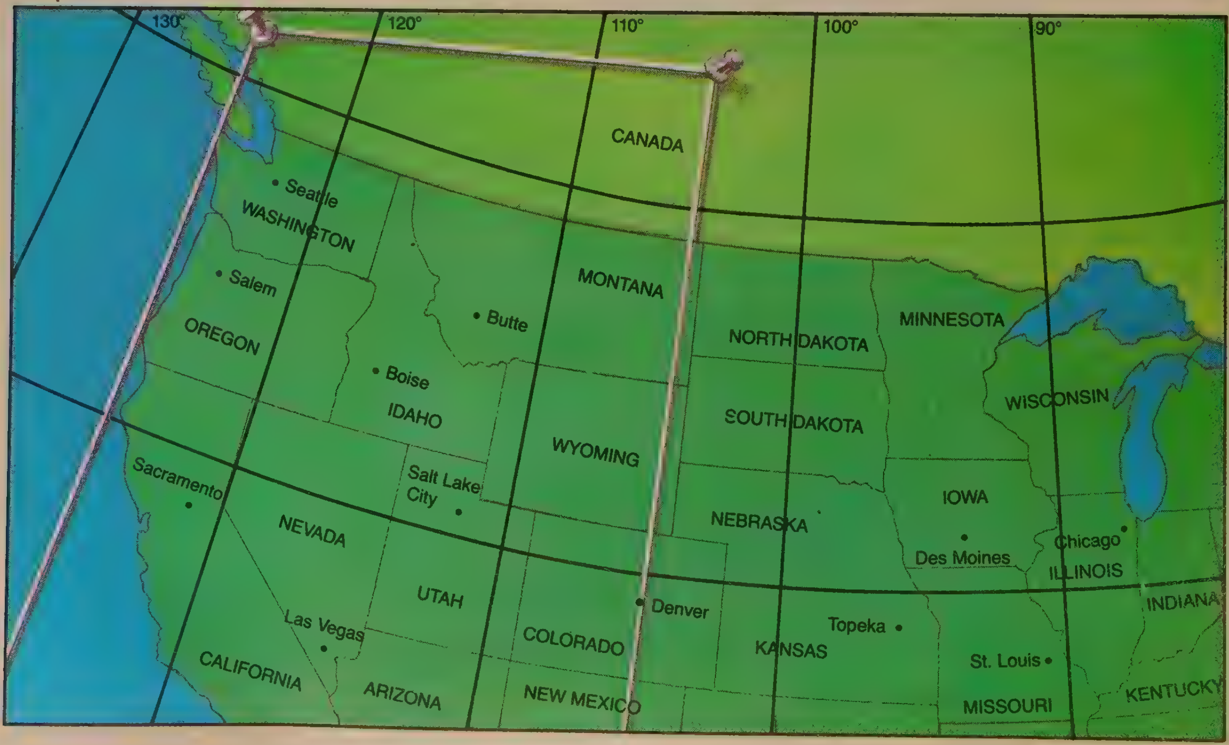
Questions

1. Philadelphia is located at 40° North latitude (40° N). Name some other major cities on the same parallel.
2. The equator is 0° latitude. Which continents does the equator pass through?
3. Denver, Colorado, is located exactly on the 105° West meridian (105° W). Vancouver, British Columbia, is almost on 125° W. Name two major cities that are located between 105° W and 125° W.
4. Which city in Australia is on the same longitude as Tokyo, Japan?
5. Which state in the United States is on the same latitude as Finland?

Conclusion

How do latitude and longitude help locate places on the earth?

Step 3



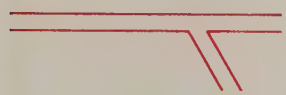
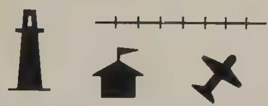
Color Codes Used on Maps		
Color	Type of Item Indicated by Each Color	Sample Map Symbol(s) for Each Color
blue	water features	
red	major roads	
green	vegetation	
black	objects made by people	
brown	land elevations	

Figure 1-25. Map symbols are often easy to understand. Which sample map symbol stands for each of these: orchard, railroad, hill or mountain, highway, school, lake?

Symbols will vary from one map to another. Sometimes, the use of colors will vary, too. But somewhere on a map will be a key that tells what any symbols used on that map stand for. Symbols are often easy to understand, even without a key. Learning to recognize map symbols and colors is not difficult.

Check yourself

1. Why are symbols on a map useful?
2. Why are different colors for map symbols useful?

North, on a map

On most maps, there is a symbol that indicates north. Generally, the symbol looks like an arrow and is identified. But is there a quick way to find north on a map? Yes. On a map, it is generally understood that north is toward the top of the map. Why is this so? As illustrated in Figure 1-26, the boundaries of most maps are nothing more than two parallels and two meridians. Meridians, as you have learned, run in a north-south direction. Parallels run in an east-west direction.

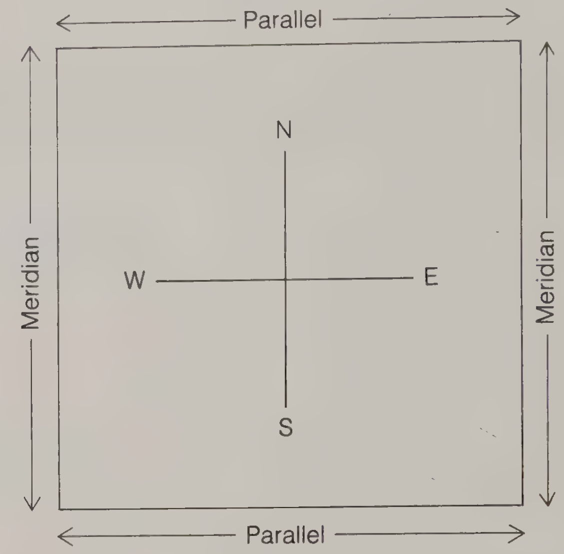


Figure 1-26. How do meridians and parallels affect the position of north on a map?

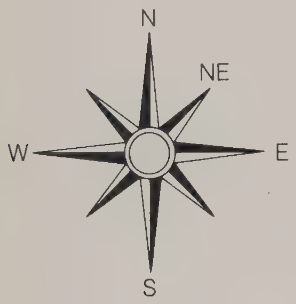


Figure 1-27. Northeast is halfway between north and east. Where is southeast?

You've probably also heard of such compass directions as northeast and southwest. Where are these directions? As shown in Figure 1-27, northeast is halfway between north and east. Southwest is halfway between south and west.

Check yourself

1. How would you know which direction is north on a map if no symbol is shown?
2. In general, which direction is toward the right on a map? Which direction is toward the upper left corner on a square map?

A scale of distances

Why do maps frequently contain a scale of distances?

Maps can be used to find distances between different places. Maps, therefore, frequently contain a scale of distances. A **scale of distances** is a ratio that shows how a distance on the map compares to the actual distance on the earth's surface.

A scale of distances may be expressed in words. For example, "One centimeter equals ten kilometers." That tells the user of the map that a distance of one centimeter on the map is equal to ten kilometers on the earth's surface.

A scale of distances may also be expressed in numbers, either as a fraction (1/100 000) or as a ratio (1:100 000). That tells the reader that 1 unit of measure on the map equals 100 000 of the same units of measure on the earth's surface. If the unit

of measure is centimeters, then one centimeter on the map equals one kilometer on the earth's surface.

If you were asked to find the distance between two points on a road map, you would probably use a graphic scale of distances. A **graphic scale of distances** consists of a line that is divided into equal parts. Each part of the line is marked in some type of units. Figure 1-28 shows an example of a graphic scale of distances in kilometers.

Figure 1-28. On a map containing this scale of distances, 1 cm on the map is equal to 1 km actual distance on the earth's surface. What is this kind of scale of distances called?

Check yourself

1. What are three different ways in which a scale of distances can be expressed?
2. Suppose you needed to find the distance between two points on a road map. What feature on a road map would make it easy for you to do this?
3. Look at the graphic scale of distances in Figure 1-28. What actual distance on the earth's surface would be indicated by 2.5 cm ?

Topographic maps

What are topographic maps?

The earth's surface is not all the same level. The earth's surface has many ups and downs. It has plains, mountains, valleys, and many other features which you have seen. There are maps that show the ups and downs and the shapes of the earth's surface features. These maps are called **topographic maps.** The word *topographic* comes from two Greek words that mean a place *(topos)* and a representation by means of lines *(grapha)*.

The shapes and elevations, or the **topography**, of a place can be indicated on a map in a number of ways. But the most accurate way is to use contour lines. A **contour line**, which is colored brown, connects places that have the same **elevation**, or

the same height above sea level. Any land elevation is always measured from the level of the sea, which is zero elevation. Contour lines also indicate the shape of land features at various elevations.

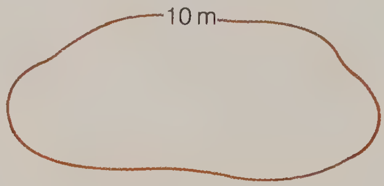


Figure 1-29. On a topographic map, this drawing indicates an oval-shaped elevation that is 10 m above sea level. How can you tell that the elevation is oval shaped?

Contour lines are not drawn for every separate elevation above sea level. Contour lines are drawn only at certain regular intervals of elevation. Each interval, which is called the contour interval, might be 5 m apart, or 10 m apart, or even 20, 25, 50, or 100 m apart. The **contour interval** is the difference in elevation between any two contour lines on a topographic map. The contour interval in Figure 1-30 is 10 m.

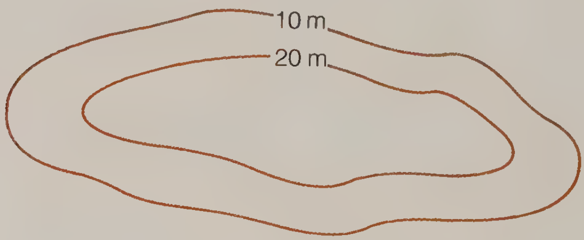


Figure 1-30. The contour interval is the difference in elevation between contour lines. In this drawing, what is the contour interval?

Figure 1-31 shows another feature that is possible to show on a topographic map. Location Z on the map is a hole or depression. This is shown on the map by means of the short brown lines that are drawn from the contour line. These little lines, which indicate direction of slope, are called **hachures**, pronounced either (huh-SHOORZ′) or (HASH′-oorz).

Is it necessary to number every contour line?

There is another feature that you will notice as you look at various topographic maps. It is not necessary to number every contour line. In some cases, all those numbers would clutter the map and make it unreadable. One solution is to number only every fifth contour line and to make that numbered line a darker brown.

Figure 1-31. The little brown lines around location Z are called hachures. What do they indicate about location Z?

Here are a few simple rules about contour lines and contour intervals.

1. Contour lines always make a closed circle. If a contour line ends on the side of a map, it would be continued on the next map.

2. Contour lines inside the closed contour lines are always higher, unless otherwise indicated by hachures.

3. Contour lines can never cross.

4. Closely spaced contour lines indicate a steep slope. Contour lines that are far apart indicate a gentle slope.

What do closely spaced contour lines indicate?

5. A contour interval is always an even multiple, such as an interval of 10 or 20.

6. Once established, the contour interval on a map never changes.

7. Contour lines always bend toward the higher elevation when they cross a stream.

Check yourself

1. How does a topographic map differ from other kinds of maps?
2. Why do contour lines indicate changes in shape as well as elevation?

Careers Earth Scientist / Cartographer

Earth-science-related careers are many and varied. This aerospace worker is preparing equipment for a wind-tunnel test.

Earth Scientist As you will discover in the course of this book, careers related to earth science are many and varied.

Within earth science, there are careers for people who want to become specialists in a particular earth science. Oceanographers, petroleum geologists, and aeronautical engineers are examples of people who do this kind of work.

Within earth science, there are careers for people who enjoy working with machines, instruments, and other technical equipment. Aerospace workers, weather technicians, and air-conditioning mechanics are just a few examples.

Within earth science, there are careers for people who enjoy other kinds of work. Building inspectors, owners of solar energy firms, and technical secretaries are examples of these kinds of people.

To draw accurate maps, cartographers use very precise instruments.

Cartographer Cartographers (kar-TOG′-ruh-ferz) are people who are involved in one or more phases of map making, which include planning, researching, designing, and drawing maps.

Cartographers make all kinds of maps. Topographic maps, geologic maps, road maps, and aeronautical maps are just some of the kinds of maps needed by various groups of people.

If you are interested in maps and in communicating information through technical drawings, then maybe you would like to learn more about map making.

Since maps constantly need revision, cartographers are in demand. They are employed by the U.S. government in several different agencies. Highway departments, mining and oil companies, and map-making firms are also in need to cartographers.

To become a cartographer you should have several years of high school mathematics. Drafting and photography would also be helpful. Not all jobs in the field of cartography require a college education.

Different ways to find north

Suppose you did not have a map with a north indicator or a map with parallels and meridians. Are there any other ways to find north?

You can use the shadow of a stick or pencil to find north. If you have ever observed the shadows of trees, buildings, or even people, you probably have noticed that shadows change in length throughout the day. When during the day do you think that you will find the longest shadows? When do you think that you will find the shortest shadows?

The sun is always directly south of you when a shadow is the shortest. This is very close to noon, by the clock, every day. By observing a shadow when it is the shortest, you can tell where south is located. North, then, would be directly in line with the shadow. The shadow at its shortest provides you with a north-south line.

Figure 1-32 shows how you can use the hour hand of a watch to find north. Place the watch flat on the ground with the hour hand pointing in the direction of the sun. South is the point halfway between the hour hand and the 12 on your watch dial. (If you are on daylight-saving time, then you must use the 1 rather than the 12 on your watch dial.) Again, once you have found south, north will be exactly opposite.

You can also use a special instrument called a **compass** to find north. If you do use a compass, however, you will need to make some type of adjustment or correction. This is because the earth has more than one North Pole.

One of the earth's North Poles is called the **North Magnetic Pole.** The direction from where you are to the North Magnetic Pole is called **magnetic north.** As shown in Figure 1-33, a compass needle points to magnetic north.

Another of the earth's North Poles is called the **North Geographic Pole.** The North Geographic Pole is the point where all the meridians meet. The direction from where you are to the North Geographic Pole is called **true north.** True north is the north that is used for finding and for giving the location of places on the earth.

The North Magnetic Pole is located in northwestern Canada, about 1600 km from the North Geographic Pole. That is why

Library research

The earth is like a huge magnet. Prepare a report on the earth's magnetism.

Toward which north does a compass needle point?

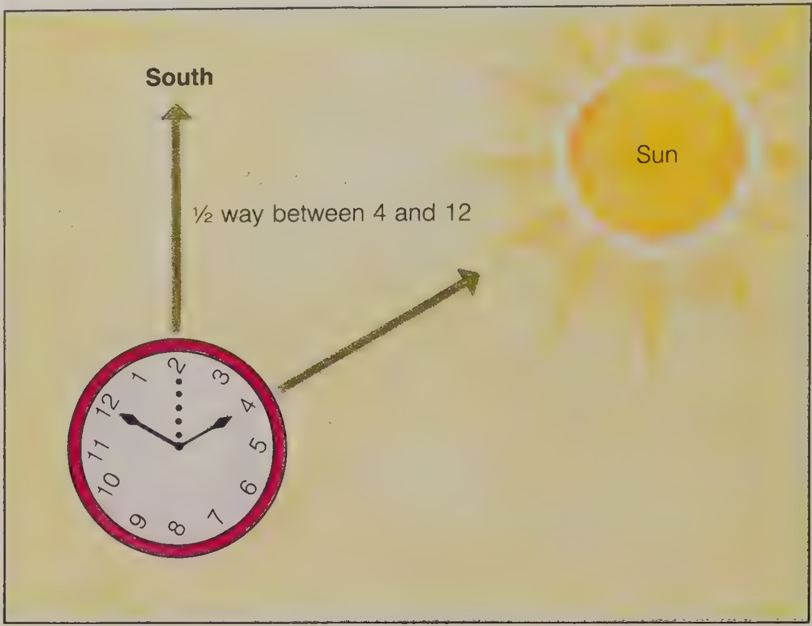


Figure 1-32. How can a watch be used to find north and south?

if you had a compass and followed the direction the needle pointed, you would not be going exactly true north. To go true north, you would need to take into account the difference between true north and magnetic north.

The difference between true north and magnetic north is called the **magnetic declination,** or magnetic variation. As shown in Figure 1-33, magnetic declination varies from one

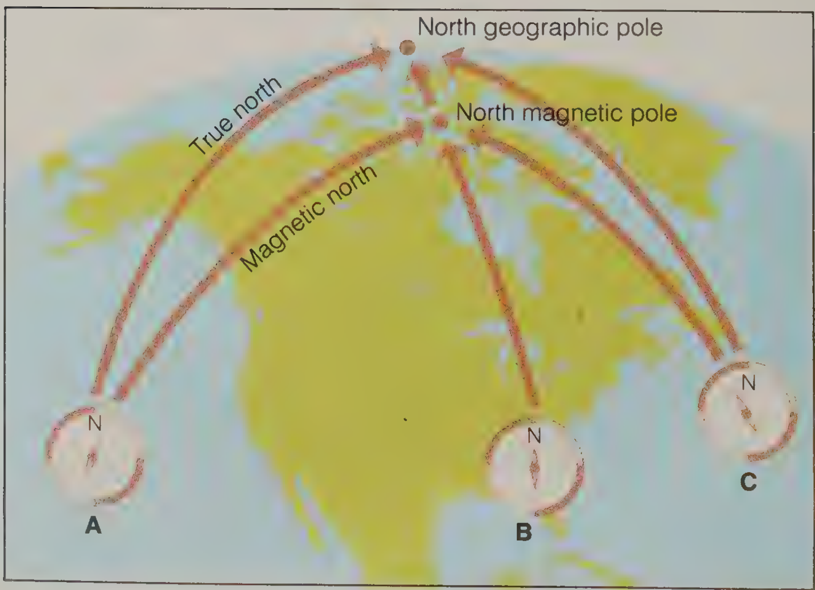


Figure 1-33. The earth has more than one North Pole. Which North Pole does a compass needle point toward?

location to another. In Figure 1-33, Location A has a declination of about 20° east. To make the N on your compass point true north at Location A, you would first line up the N with the north-seeking end of the compass needle. You would then need to turn the compass about 20° to the left. Location B has no declination at all. Location C has a declination of about 20° west.

To find true north from a compass direction, you need to know the magnetic declination for your location. Some maps provide the magnetic declination for the area that is mapped out. To show magnetic declination on a map, a symbol like the one in Figure 1-34 is placed somewhere along the bottom of the map.

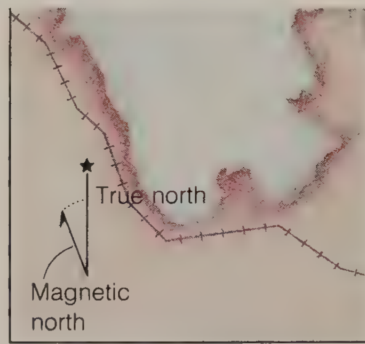


Figure 1-34. Some maps provide the magnetic declination for the area covered on the map. Is the magnetic declination shown here east or west of true north?

The earth's magnetic poles can be considered like the north and south poles of a bar magnet, with the earth itself as a giant electromagnet. The earth's magnetism may be caused by the earth's rotation acting on a liquid outer core of iron and nickel around a solid inner core of iron and nickel. The magnetic poles differ from the geographic poles for several reasons. For one, the earth's magnetic poles are continuously wandering over the polar regions. According to data from the Department of Energy Mines and Resources in Ottawa, the North Pole has journeyed northwest 800 km since 1904. Geophysicists attribute this migration to motion of the earth's fluid outer core.

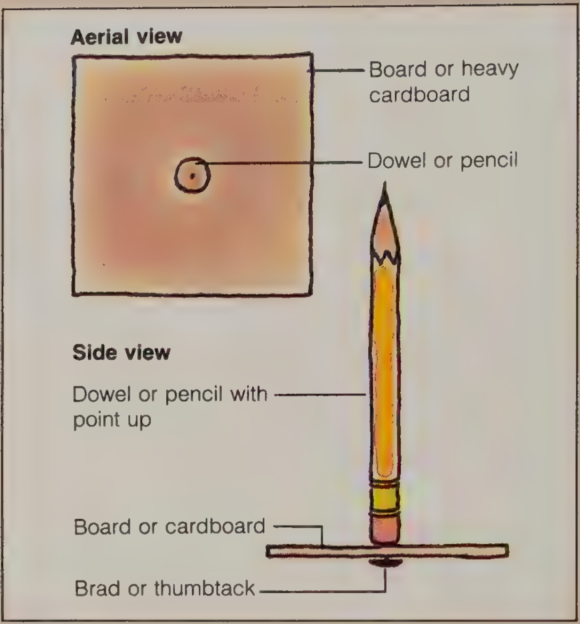
Another cause of difference between the geographic poles and the magnetic poles has to do with large-scale movements of the earth's lithospheric plates. This movement will be discussed in Chapter 10, The Restless Crust.

For the benefit of navigators, it is necessary to locate the magnetic poles from time to time. In May, 1984, the average position of the North Pole was 77° North and 102.3° West. In 1973, the pole was at 76° North and 100.6° West.

Check yourself

1. If the hour hand on your watch is pointed toward the sun and it is noon, where is north?
2. To find true north from a compass direction, why is it necessary to know the magnetic declination at your location?

Activity Using a Shadow Stick to Find a North-South Line



Materials

piece of flat board or heavy cardboard
chalk
pointed stick (dowel) or sharpened pencil
nail or thumbtack
pencil for marking
protractor

Purpose

To find the geographic north-south line using shadows cast by the sun.

What to Do

1. Find a flat surface that is paved and in direct sunlight between 11 a.m. and 1 p.m. (or between 12 and 2 p.m., if you are on daylight-saving time).
2. On the pavement, mark off an outline of your board with a piece of chalk.
3. Make a dot on the pavement along one of the chalk lines. Make a corresponding dot on the board. (If the board gets moved, the dots will help you to return it to its exact position.)
4. Make a black x in the center of the board where you will put the dowel or pencil. Using the nail or tack, attach the dowel or pencil to the board as shown. You can use a protractor to make sure the dowel or pencil is straight up and down.
5. Place the board in direct sunlight about one hour before noon. Put a small x at the top of the shadow of the stick or pencil. Write the time above the x.
6. Repeat the procedure every fifteen minutes until one hour after noon.
7. After placing all the x's on the board, connect them with a smooth line. This line must be drawn carefully.
8. Mark the point on the curved line where the shadow is the shortest—that is, where the point at the end of the shadow is closest to the stick. Draw a line from this point to the stick. This is your north-south line.
9. You might want to repeat this activity later in the year.

Questions

1. At what time was the shadow the shortest? Was it exactly at noon?
2. The sun appears to move from east to west. In what direction did your shadow move?
3. Where is the sun when the shadow is the shortest?

Conclusion

A shadow stick can provide much information about the sun and the earth. Explain.

Section 3 Review Chapter 1

Check Your Vocabulary

compass
contour interval
contour line
elevation
equator
globe
graphic scale of distances
hachures
latitude
longitude
magnetic declination
magnetic north
map
map projection
meridian
North Geographic Pole
North Magnetic Pole
parallel
prime meridian
scale of distance
topographic map
topography
true north

Match each term above with the numbered phrase that best describes it.

1. Toward the North Geographic Pole
2. An instrument for locating magnetic north
3. Short lines that indicate direction of slope
4. East-west line parallel to the equator
5. Line indicating the same elevation
6. Ratio of map distances and actual distances
7. Height above sea level
8. Elevations and shapes of land features
9. Line divided into units of distance
10. Distance north or south of the equator
11. The North Pole indicated by a compass
12. A map that shows land features
13. Point where all meridians meet
14. Difference between contour lines
15. A flat representation of the earth's surface
16. Distance from true to magnetic north
17. Line that circles the earth at 0° latitude
18. Direction toward the North Magnetic Pole
19. A north-south line that crosses the equator
20. A physical model of the earth
21. An attempt to represent the earth's curved surface on a flat surface
22. Distance east or west of the prime meridian
23. The imaginary north-south line that passes through Greenwich, England

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. _?_ are a simple way to indicate on a map various features on the earth's surface.
   a) Colors and symbols
   b) Arrows
   c) Parallel lines
   d) Compass directions
2. If you are at 0° latitude, you are at _?_.
   a) the equator
   b) the South Pole
   c) the North Magnetic Pole
   d) the North Geographic Pole
3. On a compass, _?_ is between northwest and southwest
   a) south
   b) north
   c) east
   d) west

Check Your Understanding

1. Why is it that one degree of latitude is not equal to one degree of longitude after leaving the equator?
2. Why do closely spaced contour lines indicate a steep slope?
3. Explain the difference between true north and magnetic north.
4. If a 5.5 cm distance on a map equals 55 km actual distance, how many kilometers would be represented by 1 cm on the graphic scale for that map?

Chapter 1 Review

Concept Summary

Learning involves gathering data through observation, processing and classifying data, and forming inferences on the basis of relationships drawn from the data.

- ☐ Instruments enable us to learn data not available through direct observation.
- ☐ Classifying is a way of learning that shows relationships among observations.
- ☐ Learning often involves "educated guesses."
- ☐ Science includes all the different ways of learning.

The earth is the sum total of all earth materials and all earth processes.

- ☐ All three forms of matter—solid, liquid, and gas—are found on the earth.
- ☐ The earth can be considered in terms of different divisions or spheres.
- ☐ Between the different spheres, there is a constant exchange of energy and materials.

Earth science involves all the different sciences that study particular earth materials and processes.

- ☐ Earth science also includes astronomy, which studies the stars and planets.
- ☐ Within the earth sciences, there are increasingly specialized areas of scientific investigation.

The metric system is an accurate international system of measuring that is based on multiples of ten.

- ☐ Under the name of the International System of Units (SI), the metric system can be revised as needed.
- ☐ The SI units used in the metric system are based on unchanging standards of measure.

Maps are graphic representations of all or part of the earth's surface.

- ☐ Maps can indicate location, direction, distances, relative sizes, and topographic features.

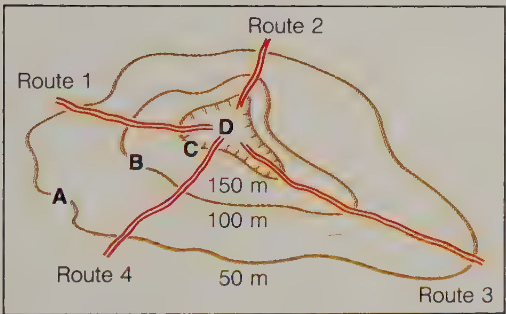
Putting It All Together

1. Describe how the following apply to scientific investigation: observation, instruments, evidence, classifying, inference, hypothesis, theory.
2. Name and describe four major divisions or layers of the earth.
3. Name five "earth sciences" and relate them to the major divisions or layers of the earth.
4. Give three requirements of a good measuring system.
5. On a separate piece of paper, copy and complete each of the following equations:
   a. 742 cm = _?_ m
   b. 1055 mm = _?_ m
   c. 0.85 m = _?_ cm
   d. 6.82 m = _?_ cm
   e. 0.43 m = _?_ mm
   f. 128 cm = _?_ mm
6. Explain how weight and mass are different.
7. Describe how to find the volume of an irregularly shaped object.
8. A substance has a volume of 16 cm^3 and a density of 2 g/cm^3. What is its mass in grams?
9. List three ways that meridians differ from parallels.
10. a. List two ways in which a map differs from a globe.
    b. Explain how a topographic map differs from other kinds of maps.

Apply Your Knowledge

1. Explain why making inferences is a key process of science.
2. Given: A block of aluminum has a mass of 54 g and a volume of 20 cm^3. Its density is 2.7 g/cm^3. Show that the density does not change if the block of aluminum is cut in half and you use only one half.

3. If the earth's circumference is 40 000 km, show that 1° of latitude equals about 111 km.
4. Using the sample map, answer these questions:
   a. What is the contour interval used on the map?
   b. Which is higher in elevation, location C or location D? How do you know?
   c. To reach location D, which route would you follow if you wanted the steepest climb? Which route would you pick if you wanted the gentlest climb? How do you know?



5. Draw a topographic map of the sea coast area shown at the beginning of Chapter 5 Section 3, on page 35. Assume that the highest part of the cliff is 20 m above sea level, and the highest point on the road is 54 m. Estimate the approximate levels of contour lines you could use. What altitude would the contour line be at the edge of the sea?

Find Out on Your Own

1. Make a list of direct and indirect observations for some object in the room. See if others can identify the object from your observations.
2. Observe any instrument you want. Discover as much as you can about this instrument. Report to the class about this instrument. Tell what the instrument is used for and teach others how to use it.
3. Invent your own system of measurement. Measure some common objects with your units of measure. Explain your system to the class. Describe some of the problems in making your system of measurements.
4. Eratosthenes lived over 2000 years ago. He found the circumference of the earth. Use his method and make your own measurements to determine the size of the earth.
5. Using a rubber ball, devise a system to locate positions and places.

Reading Further

Ardley, Neil, et al. *Why Things Are: The Simon and Schuster Color Illustrated Question and Answer Book*. New York: Julian Messner, 1984.

A good reference to a variety of earth science topics. Designed to arouse interest in scientific material. Well illustrated.

Bell, Neill. *The Book of Where or How to Be Naturally Geographic*. Boston: Little, Brown, 1982.

Can be used for learning to read maps and a compass. Humorous and well illustrated.

Beller, Joel. *So You Want to Do a Science Project!* New York: Arco, 1982.

A guide to performing worthwhile scientific projects.

Herbert, Don. *Mr. Wizard's Supermarket Science*. New York: Random House, 1980.

A delightful collection of experiments based on materials in a local supermarket.

National Geographic Society. *Hidden Worlds*. Washington, DC: National Geographic Society, 1981.

This book describes modern techniques that give information not visible to the eye about the world and the universe. Photographs are designed to arouse interest in the world about us.

Chapter 2

Earth Materials

Section 1
Minerals

The ancient Greek philosopher Empedocles (492–432 B. C.) considered the earth to be made up of four basic elements—earth, air, fire, and water. Later in this course, you will study the earth's air, fire, and water. In this chapter, you begin your study of the solid earth—the earth's crust.

Scientists of more recent times have found ninety-two elements that occur naturally among earth materials. These ninety-two elements are usually found in combinations (or compounds) called minerals.

Section 2
Rocks

The earth's crust is made of rock. Under all land areas and all ocean basins is rock.

The earth's rocks are made of different combinations of the earth's minerals. Because of ongoing earth processes, the earth's rocks are being continually recycled. Some are broken down and later cemented together. Some are melted and then cooled. Some are subjected to such heat and pressure that the minerals in them are changed.

Section 3
Using Earth Materials

The earth's rocks, minerals, and other materials have been recycling for billions of years. People's use of these materials affects this cycle. Some materials are being used faster than they can be replaced by natural earth processes.

For a time, the supply of earth materials was treated as if unlimited. Today, however, people are becoming aware of the balance between what is removed from the earth and what remains in the earth for the future.

Cities are a combination of both the natural and the manufactured. In the picture of Rio de Janeiro, Brazil, on the facing page, which objects occurred naturally? Which were made by people?

Section 1 of Chapter 2 is divided into five parts:

Figure 2-1. People distinguish one mineral from another on the basis of physical properties. What physical properties do you think a person might use to describe the specimen of the mineral fluorite shown in the photograph?

Figure 2-2. This photograph shows a specimen of copper ore. Because copper contains only copper atoms, it is an element rather than a compound.

The title of Chapter 2 is "Earth Materials." If you look up the word *material* in your dictionary, you will probably find several meanings listed. Among them will be something like "what a thing is, or may be, made of." In this section of Chapter 2, you will start your investigation of what the earth is made of.

From atoms to minerals

In asking the question "What is the earth made of?" we join a very long line of people who asked exactly the same question. Two such people lived in Greece over 2400 years ago. They were Leucippus and his pupil Democritus.

Leucippus wondered about **matter,** which is anything that occupies space and has mass. He believed that all matter is made up of very small particles called atoms. The word *atom* comes from two Greek words that mean "not" and "cut" or "divided."

Leucippus' idea that all matter is made up of atoms is called a theory. A **theory** (THEE′-uh-ree or THEER′-ee) is a way of explaining, on the basis of existing evidence, how or why something happens. No one has ever seen an atom. It is far too small for that. In fact, it would take about a million atoms, lined up side by side, to equal the thickness of the page these words are

How many atoms, lined up side by side, would it take to equal the thickness of this page?

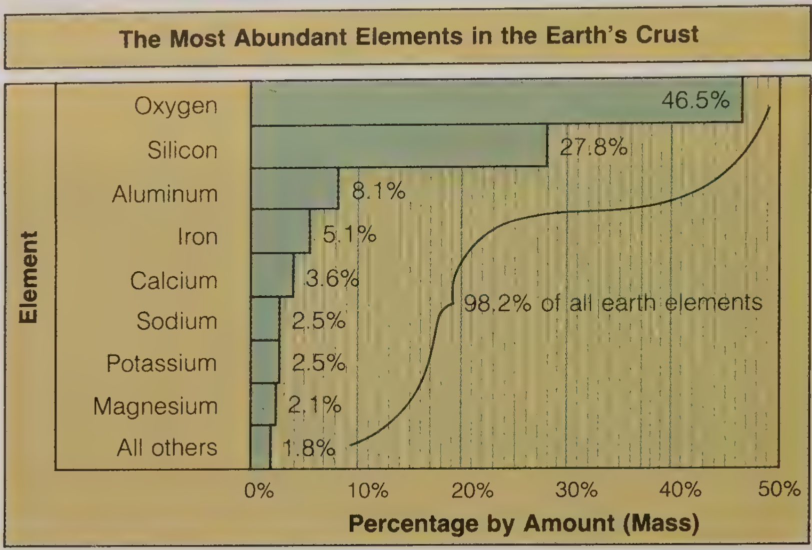


Figure 2-3. Which two elements account for almost seventy-five percent of the elements in the earth's crust?

Library research

How did Leucippus and Democritus use the atom idea to explain the properties of matter? Why did it make such good sense even though Leucippus had no evidence, directly, for atoms?

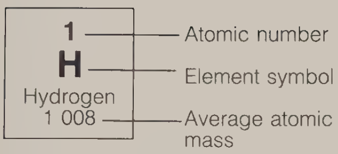


Figure 2-4. On the facing page are specimens of eight minerals: quartz (A), feldspar (B), mica (C), calcite (D), fluorite (E), gypsum (F), galena (G), and magnetite (H). Different specimens of the same mineral can differ in color. How does the color of the fluorite specimen in Figure 2-4(E) compare with the color of the fluorite specimen in Figure 2-1 on page 58?

printed on. But much that happens to matter can be explained by means of atoms.

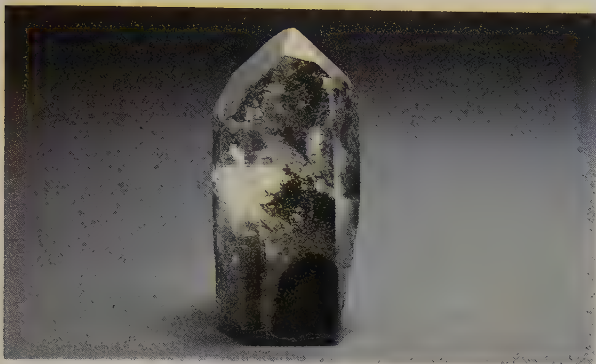
It has been discovered that there are a few kinds of matter that are made up of only one kind of atom. Copper, for instance, contains only copper atoms. Copper is therefore called an element. An **element** is a substance that contains only one kind of atom. And an **atom** can be defined as the smallest complete part of an element which contains all the properties of that element. An atom of copper, for instance, is the smallest amount of copper that still has the properties of copper.

All elements and their families can be shown in a chart called a **periodic table.** (See Appendix, page 610) They are arranged according to their atomic masses which is the mass of one atom of an element. Each element has its own symbol, a short way of writing it. Hydrogen is written "H"; carbon is "C." (See the drawing at the left)

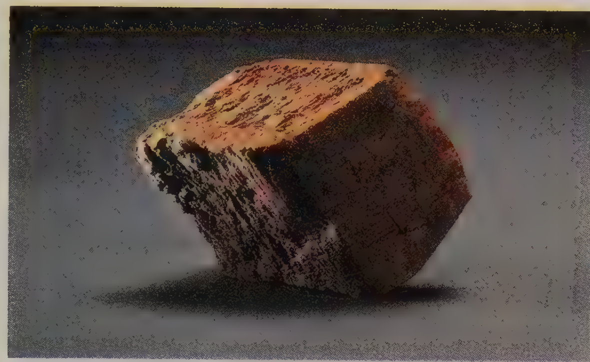
The element having the smallest atomic mass is hydrogen. It is one of the gases in air. The natural element having the greatest atomic mass is uranium. All elements listed on the periodic table having larger masses than uranium have been made in a laboratory.

Each element is designated by its atomic number, which tells its place on the periodic table. Hydrogen is number 1; uranium is number 92. These 92 elements, in different combinations, make up all the substances on earth. Eight of these elements make up over 98% of the earth's outer layer, or crust. The relative amounts of these eight elements are shown in Figure 2-3. None of them is found alone in nature

A



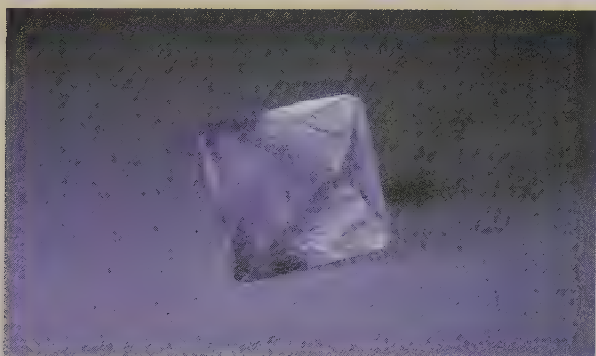
B



C

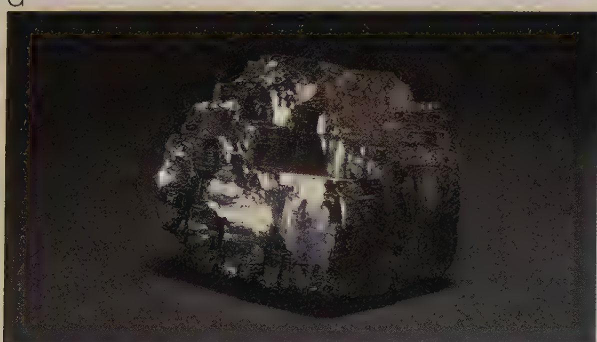
D

E

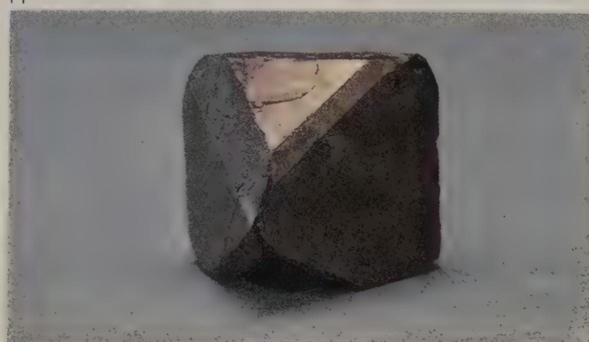


F

G



H



in any important amount as a solid substance. Instead, each is combined with at least one other element in a new substance called a compound. A **compound** is a substance that is made up of two or more elements that are joined to-

Figure 2-5. Most minerals are a mixture or combination of certain key elements. This specimen of crystalline sulfur, however, contains only the element sulfur.

gether in fixed proportions. These compounds, when found as natural solids within the earth's crust, are called by a name you may be more familiar with. They are called minerals.

There are about 2000 different minerals in the earth's crust. In this section, you will focus your attention on eight minerals: quartz, feldspar, mica, calcite, fluorite, gypsum, galena, and magnetite. Figure 2-4 shows specimens of those minerals. The photographs show some of the physical properties of these particular eight minerals.

Check yourself

1. For what purpose would a scientist use a theory?
2. How does an element differ from a compound?

What are minerals?

As just mentioned, there are about 2000 different minerals in the earth's crust. And, as you can see from the pictures of the eight minerals on page 61, minerals differ from each other. Minerals come in different sizes, shapes, and colors. Minerals differ in other ways, too. Some are harder than others. Some are heavier, or denser, than others. Some have shinier surfaces than others.

What four things do all minerals have in common?

Despite the great number of minerals and despite the many differences among minerals, all **minerals** have four things in common. 1) All minerals are made up of key elements. 2) All minerals are natural. 3) All minerals are inorganic. 4) All minerals are crystalline solids.

Key elements. Each mineral is a mixture or a combination of certain key elements. The mineral quartz, for example, is made up of the elements silicon and oxygen. There are a few minerals that are made up of only one element. Diamond, crystalline gold, and crystalline sulfur are single-element minerals. But single-element minerals are not very common.

Natural. Minerals are natural. They are found in nature, not made by people. People have learned how to join together the elements found in some minerals and make what is called a synthetic mineral. The word *synthetic* means that its elements were joined together in some way other than by nature. Synthetic quartz, rubies, and diamonds are made this way for use

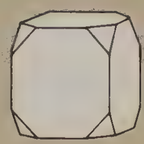
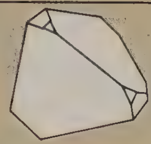
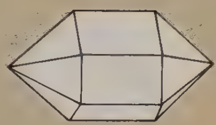
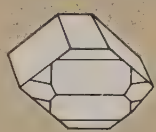
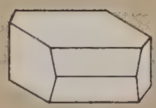
System Name	Example Mineral Crystals	Axes
Isometric or cubic system	 Galena	3 axes All of equal length All at right angles
Tetragonal system	 Chalcopyrite	3 axes 2 of equal length All at right angles
Hexagonal system	 Quartz	4 axes 3 of equal length The fourth one at right angles to the other three
Orthorhombic system	 Olivine	3 axes All different lengths All at right angles
Monoclinic system	 Gypsum	3 axes Lengths variable 2 at right angles
Triclinic system	 Microcline	3 axes All different lengths None at right angles

Figure 2-6. Mineral crystals can be considered according to one of six general systems. Which system do quartz crystals belong to?

in industry. But because synthetic minerals are made by people and do not occur naturally, they are not real minerals.

Inorganic. All minerals are **inorganic,** which means they are not organic. Most compounds made by living things are organic and are not minerals. Coal is not a mineral because it is made from organic plant remains. Bones, teeth, and shells are the only common parts of living things that are made of minerals. Most minerals form from a combination of atoms without the help of plants and animals.

What are the only common parts of living things that are made of minerals?

Crystalline solid. All minerals are crystalline solids. A **crystalline solid** is a solid substance whose atoms are locked into fixed

patterns that repeat in three dimensions—height, width, and depth or thickness. Mineral grains form by atoms attaching themselves in a three-dimensional pattern. The three-dimensional pattern is related to one of the six systems shown in Figure 2-6. Each system is distinguished by a set of imaginary internal lines called axes. When the mineral grains have complete freedom to form in any direction, the atoms of the mineral produce a certain shape by lining up along these axes. These solid shapes are **crystals.**

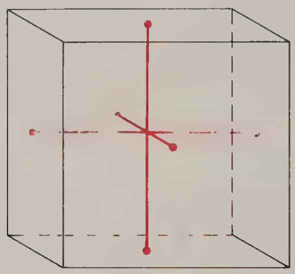


Figure 2-7. The atoms of a cube-shaped crystal line themselves up along three imaginary lines called axes. In this drawing, the three red lines represent the axes. How do the lengths of the three axes compare?

In many mineral samples that you will look at, you will see no crystals at all. Rarely are minerals found as separate crystals large enough to be seen without special equipment. Some minerals occur as masses of crystals so small that they can be seen only with a microscope. Minerals that do not have complete freedom to grow may not form crystals at all. The mineral grains, however, are still crystalline solids and can be studied with a microscope or X-rays.

Check yourself

1. Why isn't coal a mineral?
2. All minerals are crystalline solids, but not all minerals are in the form of crystals. Explain.

Silicate minerals

Minerals can be arranged into classes according to key elements that are found in each member of a class. The **silicate minerals** (SIL′-uh-kayt′ MIN′-er-ulz) form the most

common class of minerals. All silicate minerals contain the elements silicon and oxygen.

What two elements do all silicate minerals contain?

The basic building block of all silicate minerals is a grouping made up of one silicon atom and four oxygen atoms. This grouping of atoms, shown in Figure 2-8, is known as a silica tetrahedron. The word *tetrahedron,* whose plural form is *tetrahedra,* comes from two Greek words that mean four *(tetra)* sides.

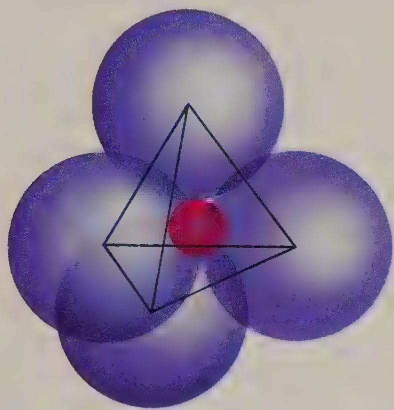


Figure 2-8. The basic building block of all silicate minerals is the silica tetrahedron, which is made up of four oxygen atoms and one silicon atom.

The quartz, feldspar, and mica pictured on page 61 (specimens A, B, and C) are common silicate minerals. From just those three examples, you can see that silicate minerals can look very different from each other.

Silicate minerals can look different from each other because they contain different key elements. Quartz, for example, contains oxygen and silicon. Feldspar contains oxygen, silicon, aluminum, and sodium, potassium, or calcium. Biotite mica contains oxygen, silicon, aluminum, iron, potassium, and magnesium.

Silicate minerals can also look different from each other because of the way their silica tetrahedra are arranged. In some kinds of silicate minerals, the tetrahedra occur as separate units. In other kinds of silicate minerals, the tetrahedra join together into pairs, rings, chains, sheets, or even complete box-shaped networks. Garnet and quartz, shown in Figure 2-9, are both silicate minerals. They look different, however, and are different minerals because of slightly different chemical composition and because their atoms have joined together in dif-

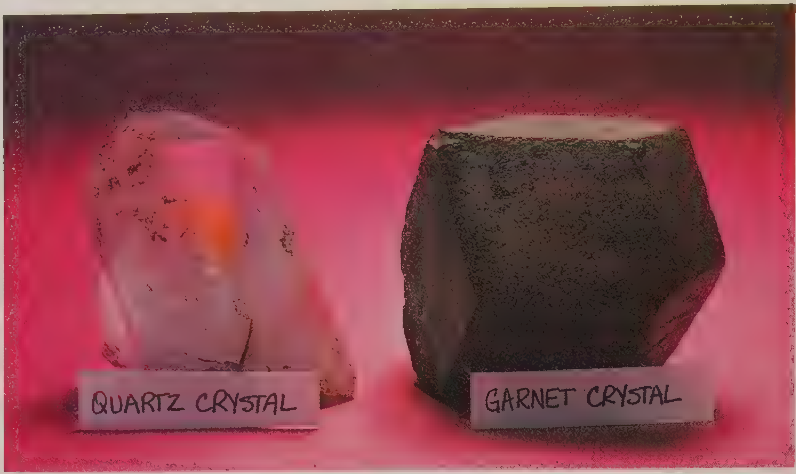


Figure 2-9. Garnet and quartz are different kinds of silicate minerals. Why are they different minerals?

ferent ways. Garnet forms according to the isometric system, and the tetrahedra are separate units. Quartz belongs to the hexagonal system, and the tetrahedra form a box-shaped network.

Library research

Make a list of all the different varieties of the mineral quartz and some of the ways quartz is used.

Silicate minerals, and all other minerals as well, can also look different from each other because of impurities. **Impurities** are atoms of elements other than the key elements of a mineral. You might think of these impurities as sneaking in while the crystals are forming. Impurities, which you can expect to find in any mineral, cause the different colors that are found among samples of the same mineral. Impurities in the mineral diamond can cause it to be pale yellow, blue, red, or even black. Regardless of color, all are the same mineral—diamond.

Check yourself

1. What is the composition and arrangement of atoms in the basic building block of silicate minerals?
2. What causes silicate minerals to be different from each other? List two causes.
3. How can impurities affect the appearance of a mineral?

Nonsilicate minerals

How have nonsilicate minerals been arranged into classes?

Nonsilicate minerals, as their name states, are all the minerals that are not silicates. Five nonsilicate minerals (calcite, galena, magnetite, fluorite, and gypsum) are pictured in Figure 2-4 on page 61. Nonsilicate minerals have been arranged into classes according to key elements within each class. Each of the five

pictured minerals is an example of a different class of nonsilicate minerals.

The carbonate minerals make up one class of nonsilicate minerals. All carbonate minerals contain the key elements carbon and oxygen. Calcite, which is calcium carbonate, is a carbonate mineral.

The sulfide minerals make up another class of nonsilicate minerals. A key element of all sulfides is sulfur. Galena, which is lead sulfide, is a sulfide mineral.

The oxide minerals are also a class of nonsilicate minerals. A key element of all oxides is oxygen. Magnetite, which is iron oxide, is an oxide mineral.

The halide minerals, which are also a class of nonsilicate minerals, can contain any one of several key elements. Fluorine, chlorine, bromine, and iodine are the most common key elements of halide minerals. The mineral fluorite, which is calcium fluoride, is a halide mineral that contains fluorine as a key element.

The sulfate minerals are a class of nonsilicate minerals, too. All sulfates contain sulfur and oxygen as their key elements. Gypsum, which is calcium sulfate and water, is a sulfate mineral.

Library research

Many minerals are used as precious and semiprecious gemstones. Make a list of gemstones and the minerals they come from. Also include where in the world different gem-quality minerals are found.

Check yourself

1. How do the nonsilicate minerals differ from the silicate minerals?
2. How (on what basis) are the nonsilicate minerals grouped into classes?
3. Sort the following minerals into two groups—silicate minerals and nonsilicate minerals: calcite, feldspar, fluorite, galena, gypsum, magnetite, mica, quartz.

What to look for in a mineral

For an exact study of minerals, a laboratory and special equipment like microscopes and X-ray machines are used. In many cases, however, geologists can see enough with no more than a magnifying glass to identify a hand-size mineral sample. Some

How useful is a magnifying glass to a geologist?

Figure 2-10. Mica breaks easily in one direction. What is that direction called?

physical properties to look for in a mineral sample are its cleavage, fracture, hardness, color, streak, and luster.

Cleavage. The ability of a mineral to break into smooth, parallel surfaces is called **cleavage** (KLEE′-vij). A mineral may have none, one, two, or more sets of flat breaks, each set in a different direction. Each of these sets of flat breaks represents a direction of weakness in the way the atoms of the mineral are held or joined together. Each set of flat breaks is called a cleavage direction. Mica, as shown in Figure 2-10, has one cleavage direction. Calcite, on the other hand, has three cleavage directions.

Fracture. Different minerals break in different ways. Fracture is the manner in which minerals break that don't have cleavage. Certain minerals can be distinguished by their type of fracture. Quartz, for example, breaks along smoothly curving surfaces. This kind of fracture is glassy and conchoidal (kong-KOY′-dul). Figure 2-11 shows the conchoidal fracture of quartz.

Who chose the series of ten minerals that are used as standards for testing hardness?

Hardness. Certain minerals are harder than other minerals and will therefore scratch them. Hardness is the ability of a mineral to scratch another mineral. Because fluorite will scratch calcite, we know that fluorite is harder than calcite. In 1822, a German mineralogist named Friedrich Mohs chose a series of very soft to very hard minerals as a scale for hardness.

Figure 2-11. When quartz breaks, it breaks along smoothly curving surfaces. What kind of fracture is this called?

Mohs' scale, which is shown in Table 2-1, is still used today to test the hardness of a mineral.

Not everyone has the ten test minerals on the Mohs' scale. Nor is such an exact measure always needed. Here are several other standards that can also be used to test for hardness: a person's fingernail = about 2½; a copper penny = about 3 to 3½; an iron nail = about 5 to 5½.

Color. Color is likely to be the first physical property you notice about a mineral sample. But color may not help that much to identify a mineral. This is because many minerals can be the same color. Not only that, but because of trace elements, different samples of the same mineral often have different colors.

Streak. Some minerals leave a colored powder when scratched. **Streak** is the color of the powder of a mineral against a white background. This is tested by rubbing the mineral sample on a piece of unglazed porcelain and noting the color of the powder left on the porcelain. As shown in Figure 2-12, pyrite leaves a black streak on the porcelain.

The streak test works only on minerals that are softer than porcelain. Porcelain has a hardness of nearly 7. If the mineral sample is harder than the porcelain, then the powder will be not from the mineral but from the porcelain.

Luster. Different minerals reflect the light differently. The way that a mineral reflects the light is called **luster.** If the mineral reflects light like shiny metal, its luster is called metallic. Other lusters are nonmetallic and include glassy (looks like broken glass), pearly or silky (reflects light like a pearl or a piece of silk cloth), and dull (has no shine at all). Quartz, calcite, and

Activity Grouping Minerals by Hardness

Materials

copper penny

iron nail

sample of all or some of the following minerals: mica, calcite, fluorite, galena, gypsum, magnetite, orthoclase feldspar, quartz

Purpose

To learn a way to classify minerals by their physical properties.

What to Do

1. Try scratching each of the mineral samples with your fingernail. Remove all that your fingernail will scratch and sort into group A (softer than 2½).
2. After removing any samples that your fingernail will scratch, try scratching the remainder of the mineral samples with a copper penny. Remove all that a copper penny will scratch and sort into group B (harder than 2½ but softer than 3½).
3. After removing any samples that a copper penny will scratch, try scratching the remaining mineral samples with an iron nail. Remove all that an iron nail will scratch and sort into group C (harder than 3½ but softer than 5½).
4. After removing the mineral samples that can be scratched by an iron nail, label the remainder group D (harder than 5½).
5. When you have finished, check your findings against the hardnesses listed in Table 2-2. Save your findings. You will be able to use them in the activity on page 72.

Questions

1. Which minerals were in group A? group B?
2. Which minerals were in group C? group D?

Conclusion

How can studying the hardness of different substances help you identify them?

Step 1

Step 2

Step 3

Mohs' Scale of Hardness		Informal Field Test
1	Talc	Softest
2	Gypsum	
		Your fingernail (2½)
3	Calcite	
		A copper penny (3½)
4	Fluorite	
5	Apatite	
		An iron nail (5½)
6	Orthoclase feldspar	
7	Quartz	
8	Topaz	
9	Corundum (ruby and sapphire)	
10	Diamond	Hardest

Table 2-1. The ten minerals on Mohs' scale are used as standards of hardness. Which two minerals on Mohs' scale can you scratch with your fingernail?

Figure 2-12. When rubbed against porcelain, pyrite leaves a black powder on the porcelain. What is this test called?

fluorite are likely to have a glassy luster. Gypsum is likely to look silky or pearly. Galena has a metallic luster.

Crystal faces. Crystals have smooth flat surfaces called crystal faces. Smooth crystal faces can be mistaken for cleavage surfaces. They differ because crystal faces are only on the surface of the crystal. Cleavage goes all the way through the crystal. This difference can be seen along broken edges of the mineral.

Sometimes the crystal faces and cleavages in a mineral are in the same direction. Common salt is an example of this kind of mineral.

Heft. The word *heft* means weight. **Heft** is a weight test. When you pick a mineral sample up in your hand, how heavy is it compared to an equal size piece of quartz? (Or, how does its density compare to that of quartz?) If the weight of the sample is about the same as quartz, the heft is average. Using the

Activity Using Physical Properties to Identify Minerals

Materials

magnifying glass

magnet

Mohs' Hardness Scale

numbered, unidentified samples of some or all of these minerals: calcite, fluorite, galena, gypsum, magnetite, mica, orthoclase feldspar, pyrite, quartz

Purpose

To test unidentified mineral specimens for physical properties.

What to Do

1. Set up a chart like the one at the bottom of this page. Record the number of each specimen and examine it for the physical properties listed across the top of the chart.
2. Record your findings in the appropriate column.
3. Turn a mineral sample in the light so that you can see a bright reflection. This direction of flat surfaces across a break is a cleavage direction.
4. Next, turn the mineral sample in the light to see if there are other cleavage directions. If you find another, try to visualize whether it is at a 90° angle to the previous cleavage direction.
5. On your chart, record both the number of different cleavage directions and the approximate angle between each two different directions.
6. To check hardness, use the three general standards used in the activity on page 70.
7. Use the "Other" column on your chart for any unusual property that you notice, such as attraction by a magnet, crystal faces, or bubbling in vinegar.
8. For each specimen, read across the list of physical properties. Then find the mineral in Table 2-2, page 73, that has a similar series of physical properties. Write the correct mineral names in the last column of your chart.

Questions

1. Which mineral(s) can you scratch with your fingernail?
2. Which samples have a streak that is a different color from the color of the sample?
3. How can you tell the difference between clear calcite and clear gypsum?
4. In your samples of galena and magnetite, what physical properties make it easiest for you to tell which is which?
5. On which of your samples were you able to see crystal faces?

Conclusion

Do you need a large amount or a small amount of a mineral in order to identify it? Explain.

Number of Specimen	Cleavage/Fracture	Hardness	Color	Streak	Luster	Heft	Other	Mineral Name

Physical Properties of Nine Minerals							
Mineral Name	Cleavage/Fracture	Hardness	Color	Streak	Luster	Heft	Other
biotite mica	cleavage, 1 direction	2½ to 3	dark brown to black	light tan	glassy	average	forms flakes and sheets
calcite	cleavage, 3 directions, not at 90° to each other	3	white, clear, pink, blue, yellow	white	glassy	average	bubbles in dilute hydrochloric acid
fluorite	cleavage, 4 directions, at 90°	4	colorless, purple, blue, green, yellow, brown	white	glassy	average	
galena	cleavage, 3 directions, at 90°, often bent	2½	silver or lead-gray	gray to black	metallic	heavy	cleavage surfaces often bent
gypsum	perfect in 1 direction, poor in 2; not at 90°	2	clear to white	white	pearly, silky, or dull	light to average	cleavage may not be seen
magnetite	irregular fracture	6	black	gray to black	metallic to dull	heavy	attracted by a magnet
orthoclase feldspar	cleavage, 2 directions, at 90°	6	white, red, pink	white	pearly	average	may appear to have a third cleavage direction
pyrite	irregular fracture	6 to 6½	silver-gold	black	metallic	heavy	
quartz	glassy, conchoidal fracture	7	white, clear, gray, pink	white	glassy	average	crystal faces common

heft test, gypsum will appear light to average, orthoclase average, and galena heavy.

Physical properties of quartz, orthoclase feldspar, pyrite, biotite mica, calcite, fluorite, gypsum, galena, and magnetite are listed in Table 2-2. Note how inconclusive color is as a distinguishing physical property of many minerals.

Table 2-2. Which of the nine minerals in the table above bubbles in dilute hydrochloric acid?

Check yourself

1. How are minerals identified?
2. The streak test works only on minerals that are softer than porcelain. Explain.

Section 1 Review Chapter 2

Check Your Vocabulary

atom	inorganic
cleavage	luster
compound	matter
crystal	mineral
crystalline solid	nonsilicate minerals
element	silicate minerals
heft	streak
impurities	theory

Match each term above with the numbered phrase that best describes it.

1. A way of explaining how or why something happens
2. A substance made up of two or more elements joined together in fixed proportions
3. The ability of a mineral to break into smooth, parallel surfaces
4. All minerals that are not silicates
5. The way that a mineral reflects the light
6. The smallest complete part of an element with all the properties of that element
7. Anything that takes up space and has mass
8. The shape produced when mineral grains have freedom to form in any direction
9. Atoms of elements other than the key elements of a mineral
10. The color of the powder of a mineral against a white background
11. Minerals containing silicon and oxygen
12. A compound that is natural, inorganic, a crystalline solid, and made up of key elements
13. A rough-estimate weight test for minerals
14. A solid substance whose atoms are locked together into fixed patterns; true of all minerals
15. Not organic; formed, for the most part, without the help of plants and animals
16. A substance that contains only one kind of atom

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. All minerals are _?_.
   a) organic c) crystalline solids
   b) crystals d) synthetic
2. The basic building block of all silicate minerals is _?_.
   a) the silica tetrahedron
   b) crystalline sulfur
   c) the element fluorine
   d) the cleavage direction
3. When mineral grains have complete freedom to form in any direction, the atoms of the mineral produce a certain shape by lining up along a set of imaginary lines called _?_.
   a) tetrahedra c) carbonates
   b) fractures d) axes

Check Your Understanding

1. Explain why not all minerals are found in crystal form.
2. Explain why the crystal forms of different minerals have different shapes.
3. Explain how silicate minerals, carbonate minerals, and sulfide minerals differ from each other.
4. Explain how minerals can be identified without using microscopes or X-ray machines.
5. Explain how Mohs' scale is used.

Rocks Section 2

Section 2 of Chapter 2 is divided into three parts:

Where does rock come from?

The rock cycle

What to look for in a rock

Figure 2-13. These mountain peaks, photographed at sunrise from Point Languard, Switzerland, are formed of rock. Is there rock somewhere beneath you right now, as you read the words on this page?

How are minerals and rock related?

If you look around you, you probably cannot find a single specimen of the 92 elements that occur naturally in the outer layer of the earth. Nor is it likely that you can find a specimen that is made of only one mineral. But it is very likely that you can easily put your hands on a mixture of minerals that is called **rock.**

Beneath you right now, as you read the words on this page, there is rock. If you happen to be sitting on a mountaintop, you might be right on solid rock. If you are in a building with soil around and under it, beneath all soil there is a layer of solid rock. If you happen to be in a boat, there is rock beneath all rivers, lakes, and oceans on the earth.

The rocks of the earth come in many different sizes and shapes and colors. But no matter what color or size or shape, each rock has a story to tell—a story about how that rock was formed. In this section, you will learn some of that story.

Where does rock come from?

The outer layer of the earth is constantly changing. The rocky faces of mountains and cliffs are being slowly broken down into smaller particles. These increasingly smaller particles are being carried away by moving water or by wind or even by glaciers. But at the same time that parts of the earth are wearing down, other parts are building up. New rock is being formed that replaces the old. New rock is being formed from the old.

What determines the class of a rock?

Any rock that you find on earth can be grouped into one of three classes, depending on how the rock was formed. One class of rock, called **igneous rock,** is formed from hot melted materials. A second class of rock, **sedimentary rock,** is formed from sediment, which is most often small particles of rock, such as sand and gravel. **Metamorphic rock,** a third class of rock, is formed when minerals and rocks are changed by very great heat and pressure which changes the crystal structure.

Igneous rock. Rock that forms from **magma,** which is the liquid rock melt that is found in some places beneath the earth's surface, is called igneous rock. Some kinds of igneous rock, called *intrusive rock,* coarsely crystalline rocks like granite,

form when the magma cools before it reaches the surface of the earth. Other kinds of igneous rock, called *extrusive rock,* very finely crystalline rocks like basalt, form on the earth's surface from **lava,** which is what magma is called after it reaches the surface of the earth. Volcanic ash deposits form another type of igneous surface rock. The word *igneous* is from the Latin word *ignis,* which means "fire."

Figure 2-14. Some of the earth's rocks are formed from lava that cools on the earth's surface. What class do such rocks belong to?

Sedimentary rock. There are three ways in which sedimentary rock can form. Most sedimentary rock, like sandstone, is made up of particles of other rocks and minerals that have all been deposited in one place, usually by moving water. As layer builds upon layer of particles, the bottom layers become pressed together by the weight of the layers above them. At the same time, elements in the water form a cement that joins the particles of sediment together to form a solid.

Where does the cement come from that holds particles of sedimentary rock together?

Activity Forming Layers

Materials

2 test tubes, numbered 1 and 2
test-tube rack
sand
table salt
iron filings
water

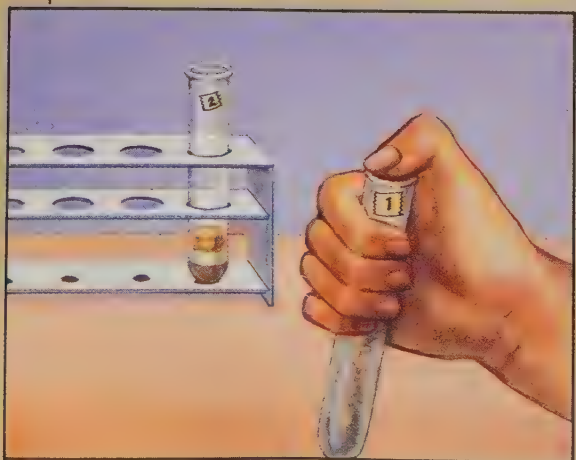
Purpose

To learn how layers form and how layers of sediment can change.

What to Do

1. Put the test tubes in the test-tube rack. Start by forming the same three layers in each test tube. Pour iron filings into each test tube until you have a layer about 1 cm thick. On top of the iron filings pour a 1-cm layer of table salt and a 1-cm layer of sand.
2. Remove Test Tube 1 from the rack. Put your thumb over the mouth of the test tube and shake the test tube hard for about 10 seconds.

Step 2



3. Tap the side of the Test Tube 1 near the bottom gently for several minutes.
4. Add enough water to Test Tube 1 to cover the sediment with 1 cm of water. Shake the tube gently for about 15 seconds.
5. Gently add water to Test Tube 2, but do not shake it. Set the test-tube rack and test tubes with sediments in a warm, dry, safe place.

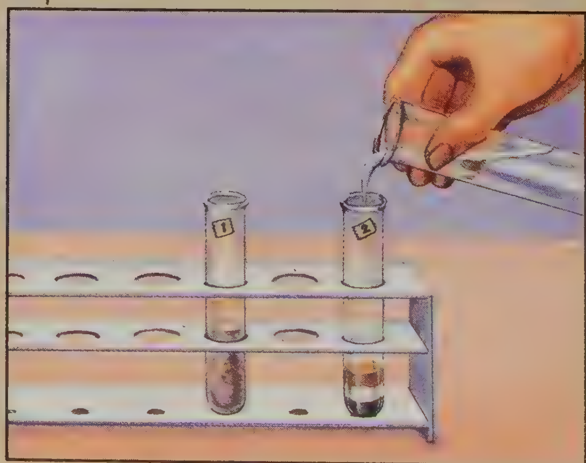
Questions

1. What properties make it easy to see layers?
2. What happened to the layers when you shook Test Tube 1?
3. When you tapped Test Tube 1, which material settled most rapidly? Why?
4. When you covered Test Tube 1 with water and shook the test tube, what happened to the salt?
5. When water was added to Test Tube 2, what happened?
6. After the water has evaporated in both tubes, describe the layers. Where is the salt?

Conclusion

How might minerals form layers of sediments?

Step 5



Not all sedimentary rock is formed from particles of rock. Some sedimentary rock, like limestone, is formed by the remains of organisms that were once alive. Other sedimentary rock (for example, rock salt and other kinds of limestone) is formed from minerals that were once dissolved in water. The minerals then formed out of the water as crystals.

Is all sedimentary rock formed from particles of rock?

The words *sediment* and *sedimentary* come from the Latin word *sedere,* which means "to sit" or "to settle" or "to come to rest." In the case of sedimentary rock, it can be either particles of rock, remains of plants or animals, or newly-formed mineral crystals that form on or settle to the bottom of the water and build up layers of sediment. Sedimentary rocks are usually made of layers.

Figure 2-15. These landforms in Monument Valley, Arizona, are made of sandstone. What class of rock does sandstone belong to?

Figure 2-16. These layers of schist were photographed at King's Canyon National Park. What could have caused the bending and folding of the rock layers?

What is an example of a metamorphic change in the insect world?

Metamorphic rock. Rock that has been changed from one kind of rock to another is called metamorphic rock. In the insect world, a butterfly completely changes its form as it goes from a caterpillar to a cocoon to an adult butterfly. This change in form is called metamorphosis.

In the world of rocks and minerals, heat and pressure can cause changes in the minerals that make up a rock. Sometimes the atoms of minerals change position, and new minerals are formed. Sometimes minerals lose or gain atoms. In either case,

the resulting rock is a metamorphic rock. The word *metamorphic* comes from two Greek words that mean "changed form."

When the atoms of a mineral change position, certain mineral grains will sometimes grow larger. Many metamorphic rocks contain very large crystals. Also, in response to pressure, the minerals in most metamorphic rocks tend to form layers. In rocks that have been under great pressure, these layers may be noticeably bent or folded.

What does the class of a rock tell you about the rock? If the rock is igneous, you know that it formed from magma. You can also tell whether the rock formed beneath the earth's surface or whether it formed from a lava flow or volcanic ash above ground. If the rock is sedimentary, you know that the rock most likely formed beneath a body of water or from desert or seacoast sands. And if the rock is metamorphic, you know that one of two things probably happened. The rock could have formed very deep below the surface of the earth, where there is great heat and pressure. Or the rock was formed by the heat from a nearby flow of magma or lava.

Library research

Find the basic differences between contact metamorphism and regional metamorphism.

Check yourself

1. Distinguish among igneous, sedimentary, and metamorphic rock on the basis of how each forms.
2. Distinguish among igneous, sedimentary, and metamorphic rock on the basis of such physical properties as layering and the appearance of particles within the rock type.

The rock cycle

Any rock you find can be grouped into one of three classes. It is either igneous, sedimentary, or metamorphic. But that rock did not always belong to the same class. The rocky face of the earth is constantly changing. Rocks and minerals are part of a huge recycling process.

Any class of rock can be changed into any other class of rock. An igneous rock, for example, can be dissolved and broken apart by weathering processes at the earth's surface. The products of weathering are either particles of rock or dissolved salts.

Library research

Expand your knowledge of rock classes to include the following: extrusive and intrusive igneous rock, clastic and nonclastic sedimentary rock, foliated and nonfoliated metamorphic rock.

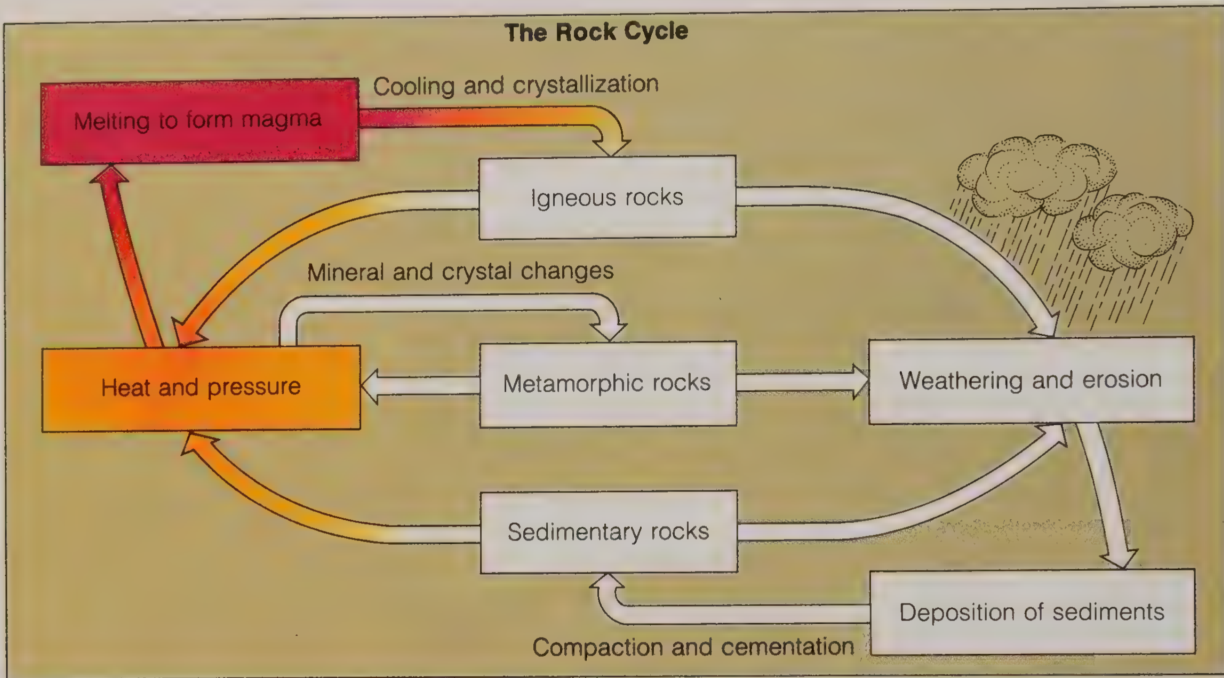


Figure 2-17. According to this diagram of the rock cycle, how many classes of rocks can be changed into sediments by weathering and erosion?

The particles of rock and the dissolved salts are deposited and built up as layers of sediments that harden to become a sedimentary rock. The sedimentary rock can become deeply buried in the earth and changed into a metamorphic rock. The metamorphic rock can then be melted by heat within the earth and be changed into magma, which later cools and hardens into an igneous rock. This process of change from one class of rock to another is called the **rock cycle.**

In the example you just read, the igneous rock at the beginning of the cycle would probably not be the same as the igneous rock at the end. The rock cycle is a cycling in the sense of a recycling. It is a redistribution of elements and minerals from one rock type to another. The rock cycle is not the kind of cycle that returns to the same point or condition after a period of time. Nor does the rock cycle always follow the same series of changes. Figure 2-17 shows the possible changes in the rock cycle and the processes needed to bring about those changes.

Two other processes not shown in Figure 2-17 are often very important parts of the rock cycle. Rocks buried deep in the earth must be raised to the surface and exposed before they

can be broken down or dissolved by the weather. And rocks near the surface must be buried to great depths in order to be exposed to the pressure and heat needed to undergo metamorphism or melting.

Check yourself

1. What are the processes that turn a sedimentary rock into an igneous rock?
2. What are the processes that turn a sedimentary rock into a metamorphic rock?
3. What are the processes that can turn a sedimentary rock into a different sedimentary rock?

What to look for in a rock

The first step in identifying a rock is to determine whether the rock is igneous, sedimentary, or metamorphic. This first step is very important, but it is not always easy because some very different rocks may look like each other. You therefore have to examine a rock for certain physical properties. In particular, you need to consider a rock's texture and its mineral composition.

The **texture** of a rock is the pattern made by the size, shape, and arrangement of the particles that are in the rock. Table 2-3 defines six common rock textures. Though sometimes called by different names, those six textures will help you describe most any rock you find.

The **mineral composition** of a rock is, as its name states, a list of the minerals that make up the rock. For a start, there are a few basic minerals to look for. Recognizing those minerals will help you to make an approximate identification, which is sometimes all that a person can make without special equipment.

How can a person learn to make approximate identifications of rocks?

Most common rocks contain silicate minerals. Silicate minerals can sometimes be recognized merely by their color. Pink or red crystals are a potassium feldspar like orthoclase. Glassy, gray to purple-gray grains are quartz. Green colors are usually amphibole, pyroxene, or olivine. The micas are little flakes.

Activity Determining the Class of a Rock

Materials

numbered samples of unidentified rocks
iron nail
magnifying glass
metal or hard plastic rod
eyedropper
10% dilute hydrochloric acid

Purpose

To use a key to determine the class of a rock.

What to Do

1. Start the key at Number 1. Follow the instructions after you answer each question.
2. Record your answer (igneous, sedimentary, or metamorphic) for each sample.
3. Do not be discouraged if some of your answers are wrong. It takes practice before a person can easily answer some of these questions. Also, some rocks are so hard to identify that even experts have trouble.

Key for Determining the Class of a Rock

1. Are any of the grains or crystals large enough to see without a microscope? *If yes, go to Number 2. If no, go to Number 15.*
2. Are the grains masses of crystals that are all grown together? *If yes, go to Number 3. If no, go to Number 11.*
3. Is the overall texture banded? *If yes, go to Number 4. If no, go to Number 5.*
4. Do the bands consist of silicate minerals like quartz, feldspar, and mica? (You can use visual tests and hardness.) *If yes, the rock is metamorphic; if no, sedimentary.*
5. Are the mineral grains silicate minerals? (You can use visual tests and hardness.) *If yes, go to Number 6; if no, to Number 9.*
6. Are there two or more abundant silicate minerals? (Consider color and hardness.) *If yes, it is igneous. If no, go to Number 7.*
7. Does the sample contain no crystal faces and consist only of quartz? (Quartz, which has a hardness of 7, will scratch glass or steel.) *If yes, the rock is metamorphic. If no, go to Number 8.*
8. Is the sample a natural glass? (Remember that glass contains no crystals.) *If yes, the rock is igneous. If no, go to Number 9.*
9. Does the sample consist entirely of calcite? (Calcite has a hardness of only 3 and will bubble in dilute hydrochloric acid.) *If yes, go to Number 10. If no, go to Number 14.*

   SAFETY NOTE: *Make sure the acid you work with is 10 percent dilute, which your teacher will provide.*
10. Is the sample white or clear? *If yes, the rock is metamorphic; if no, sedimentary.*
11. Are some of the mineral grains or crystals large enough to see? *If yes, go to Number 12. If no, go to Number 14.*
12. Are any mineral grains particles that have been cemented together? *If yes, the rock is sedimentary. If no, go to Number 13.*
13. Are the grains or crystals arranged in fine layers or bands? *If yes, the rock is metamorphic. If no, the rock is igneous.*
14. Can fine-grained parts of the rock be scratched with a nail? (Look carefully. If the nail "writes" on a very hard rock, the mark could look like a scratch.) *If yes, go to Number 10. If no, the rock is igneous.*
15. Does the rock break into thin layers when you tap it with another rock or with some other hard object? *If yes, go to Number 16. If no, go to Number 7.*
16. Does the rock have a hard, sharp, or ringing sound when you tap it with a hard rod? *If yes, the rock is metamorphic. If no, the rock is sedimentary.*

Six Common Rock Textures		
Type of Texture	Description of That Texture	Example Rocks of That Texture
coarse-grained texture	made up of mineral grains or crystals that are large enough to be seen without using a microscope	granite marble sandstone (page 87)
fine-grained texture	made up of mineral grains or crystals too small to be seen without a microscope	limestone basalt (page 87)
mixed-grain texture	made up of at least two very different-size grains	conglomerate (page 86)
glassy texture	containing no mineral crystals at all; a natural glass	obsidian (page 86)
layered texture	made up of mineral crystals all lined up in the same direction; parallel grains distributed more or less evenly within the rock	slate schist sandstone (page 87)
banded texture	made up of different minerals that are concentrated in different bands rather than distributed evenly throughout the rock	gneiss (page 87)

Table 2-3. How does the texture of granite differ from the texture of limestone?

Library research

Find out the type of rock that each of the following is made of: Mt. Aconcagua, Mt. Everest, Pikes Peak, the Great Pyramid, Stonehenge, the Parthenon.

Biotite mica is black. Muscovite mica is clear to tan. White crystals may be any of the feldspars. If a feldspar has equal amounts of sodium and calcium, it is usually gray.

Silicate minerals can also be identified by other physical properties. To distinguish quartz from a feldspar, for instance, hardness can be used. Quartz has a hardness of 7, and feldspar has a hardness of 6. Also, feldspar crystals often have flat cleavage surfaces or crystal faces, whereas quartz usually looks like clear or gray glass filling in between other mineral grains.

Figure 2-18. Obsidian is an example of a rock with a glassy texture. How would you describe the texture of conglomerate?

Figure 2-19. On the facing page are specimens of eight rocks: granite (A), gneiss (B), sandstone (C), quartzite (D), limestone (E), marble (F), shale (G), and schist (H). Considered as four pairs, each rock on the right is a metamorphic form of the rock on its left.

Calcite is also a key mineral for you to be able to recognize in a rock. Limestone and marble, for instance, are made up almost totally of calcite. Calcite is easily distinguished from quartz and feldspar because calcite has a hardness of only 3. Another easy test for calcite is one drop of dilute hydrochloric acid. Calcite will bubble readily in dilute hydrochloric acid. Calcite will also bubble in white vinegar, but it may take as long as fifteen minutes for the bubbles to form in vinegar. In dilute hydrochloric acid, the bubbles form immediately.

Pictured in Figure 2-19 are pairs of common earth rocks. In each pair, the rock on the right is the metamorphic form of the rock on the left. Which textures do you think show most clearly? Looking at each pair of pictures, how would you compare the rock on the left with its metamorphic form on the right? How are they alike? How are they different? How would you describe any patterns in the arrangement of the crystals?

If you have samples of any of the rocks pictured in Figure 2-19, how do your samples compare with the pictures of the same kind of rock? What do you think causes differences in appearance among samples of the same kind of rock?

Check yourself

1. What are the two most important physical properties to look at when identifying a rock?
2. How can you distinguish calcite from quartz in rocks?

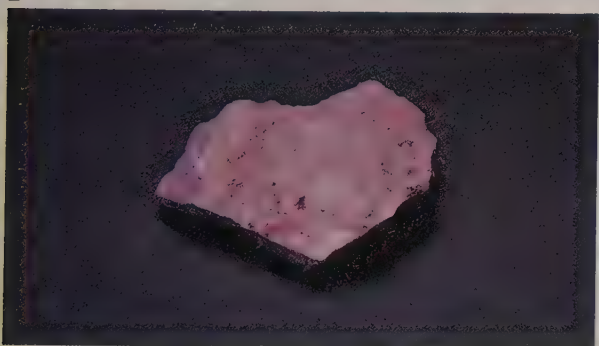
A

B

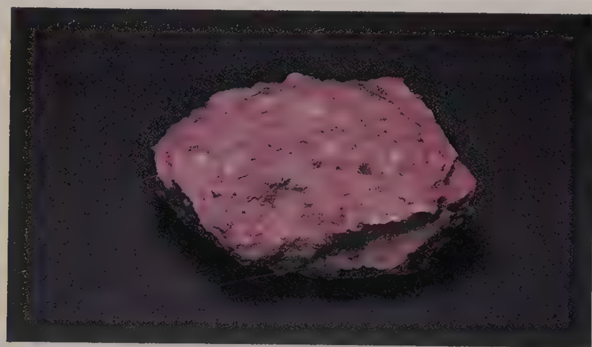
C

D

E



F



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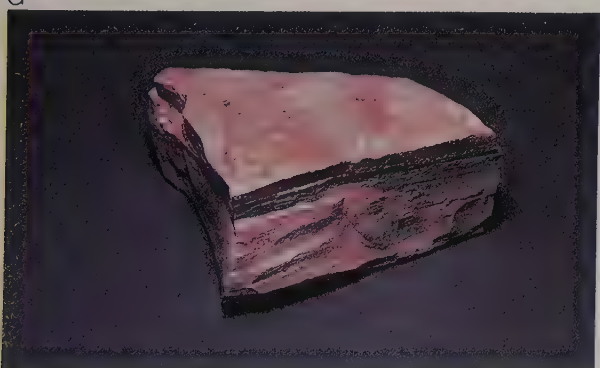

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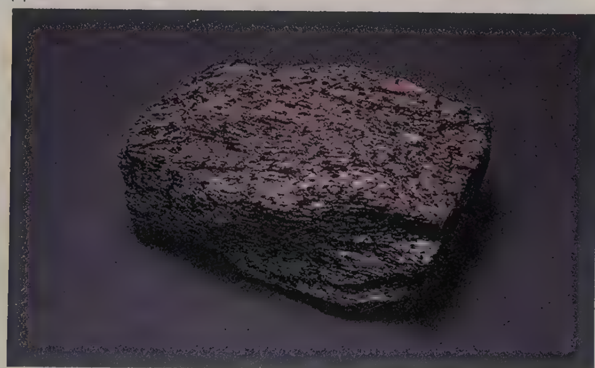


Section 2 Review Chapter 2

Check Your Vocabulary

igneous rock	rock
lava	rock cycle
magma	sedimentary rock
metamorphic rock	texture
mineral composition	

Match each term above with the numbered phrase that best describes it.

1. A mixture of minerals that is beneath all soil and water on the earth's surface
2. Rock that is formed from hot melted materials
3. Rock that is formed from sediments
4. Rock that is formed deep within the earth's crust when minerals and rocks are changed by very great heat and pressure which changes the crystal structure
5. The process by which rock is changed from one class to another
6. Liquid rock melt that is found in some places beneath the earth's surface
7. The pattern made by the size, shape, and arrangement of the particles that are in a rock
8. A list of the minerals that make up a rock
9. What magma is called after it reaches the surface of the earth

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Some __?__ rock is formed from minerals that were once dissolved in water.
   a) igneous
   b) sedimentary
   c) metamorphic
   d) igneous and metamorphic
2. Rocks are grouped into one of three classes, depending on how the rock was __?__.
   a) shaped c) colored
   b) formed d) located
3. A sedimentary rock can turn into an igneous rock by __?__.
   a) melting and then cooling
   b) weathering and deposition
   c) compaction
   d) compaction and cementation
4. Coarse-grained and fine-grained are examples of rock __?__.
   a) composition c) texture
   b) class d) salts
5. __?__ will bubble readily in dilute hydrochloric acid.
   a) Quartz c) Feldspar
   b) Calcite d) Mica

Check Your Understanding

1. Compare lava and magma. How are they similar? How are they different?
2. Explain how the three classes of rock are formed.
3. Explain in detail the rock cycle.
4. Name and describe six common rock textures.
5. In a sample of granite, how can quartz be distinguished from feldspar?

Using Earth Materials   Section 3

Section 3 of Chapter 2 is divided into five parts:

Using minerals and rocks

Using fossil fuels

Using the wind and the sun

Using water

Using atoms

Figure 2-20. This picture shows part of a Chrysler robot assembly line. Which of the objects in the picture could have been made without the use of earth materials?

How old are the earth materials used in making the most up-to-date product?

Think of any object around you that did not just happen naturally. That object, which was made by people, might be a roadway, a building, a chair, a magazine, or a pair of jeans. No matter which object you consider, that object could not have been made without earth materials.

Most products that we use are made from earth materials. Earth materials are also the source of the energy needed to run the machines that make products. The products themselves may be the very latest and most up to date. The machines and energy sources may also be very new. But the earth materials, on which the whole process depends, are very old. Earth materials have been recycling for millions of years.

Using minerals and rocks

Minerals and rocks are the source for most of the earth's metals. A few metals, such as copper and gold, can be found as pure elements in nature. But most are found as mineral compounds of either oxygen (oxide minerals) or sulfur (sulfide minerals). Metals such as chromium, tin, magnesium, aluminum, and iron come from oxide minerals. Other important metals, such as nickel, lead, zinc, and copper, come from sulfide minerals.

Metals are an important group of elements because of properties that nearly all of them possess. In general, metals melt easily. They conduct heat and electricity. They can be hammered or pressed into different shapes without breaking. And they have a certain kind of luster, or shine.

Metals are widely used today. Steel, which is made mostly from iron, has great strength. Tall buildings, long bridges, ocean liners, jet planes, and automobiles depend on steel, aluminum, and other metals for their strength. Most metals have many uses. Copper and aluminum, for example, are made into wire because they are good conductors of electricity. You can certainly think of many other products that make use of the earth's metals.

Minerals and rocks also provide a source for important nonmetals. Nonmetals, as their name indicates, are substances that are not metals. Sand, for example, is a nonmetal that is used in

making cement. Sand is also used in making glass and the silicon chips used in computers. Clay, another common nonmetal, is used in making china and pottery. Gypsum is used in making plaster and wallboard. Limestone is used in making cement, an important building material. And compounds of phosphorus

Figure 2-21. In the pictures above, each metal object on the right could be a product of the ore to its left. Specimen A is an iron ore (hematite). Specimen C is an aluminum ore (bauxite). Specimen E is a copper ore (bornite).

Figure 2-22. In the pictures above, each earth material on the left is used in the manufacture of the nonmetal product to its right. The earth materials are sand (A), clay (C), and limestone (E).

(phosphates) and of nitrogen (nitrates) are used in making fertilizers. Other uses of nonmetals include building stone, ornamental stone, and gemstones for jewelry.

Any mineral or rock from which a needed substance can be removed cheaply enough and easily enough is called an **ore.**

Figure 2-23. In this photograph, you can see how part of an open-pit phosphate mine in Florida has been restored and is being used as pasture land for animals. What factors affect the total cost of obtaining and refining ores?

Both metals and nonmetals are obtained from ores. Ores are taken from the ground by a process called mining. The place the ore comes from is called a **mine.**

There are two basically different types of mines—surface mines and underground mines. Both types of mines can be small or large. Open-pit mines are surface mines. Copper and aluminum ores are frequently mined this way. Strip mining is another type of surface mining. Large earthmoving equipment removes the surface materials to get down to the ore or fossil fuel. Coal is frequently mined this way.

A mined ore must be processed in order to obtain a useful substance. For some substances, such as gold or gravel, a simple crushing or washing is all that is needed. For other substances such as iron, copper, or aluminum, the ore must be further treated with heat, chemicals, or electricity to obtain the metal. These processing methods are referred to as refining the ore.

Not all minerals and rocks that contain a needed substance are used as sources for that substance. Much depends on cost. Sometimes it costs too much to remove the rock or mineral

Library research

Make a list of the rocks or minerals that are ores for each of the following metals: iron, aluminum, copper, lead, chrome, titanium, mercury.

Activity Separating Earth Materials

Materials

sand or sandy soil	magnet
iron filings	2 jars
water (hot and cool)	2 glass pie plates
salt	plastic rod or ruler to use as stirrer

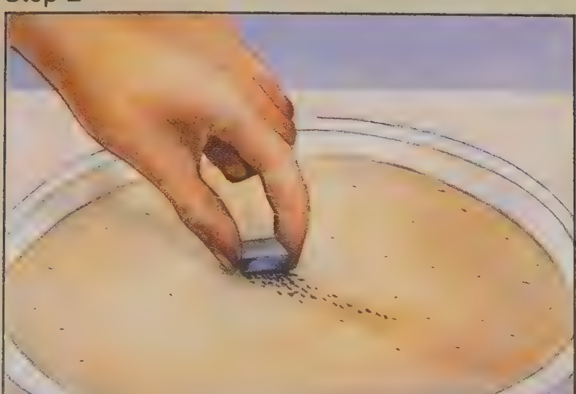
Purpose

To learn three ways to separate earth materials.

What to Do

1. In a pie plate, mix together some iron filings and some sand.
2. Drag a magnet through the mixture and note what happens.
3. In a jar, mix together more iron filings and sand and add cool water to cover the mixture to a depth of about 5 cm or more.
4. Stir the mixture rapidly and then let the sand and iron settle out.
5. In a jar, mix together some sand and some table salt. Add hot water to cover the mixture to a depth of 2-3 cm. Stir the mixture well.
6. Pour off the water into a pie pan. Let the water evaporate until the pan is completely dry.

Step 2



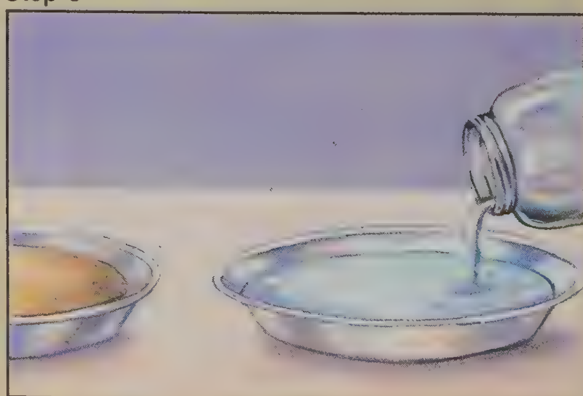
Questions

1. When you dragged the magnet through the iron and sand mixture, what happened to the iron? What property of iron allows you to separate it from sand in this way?
2. When you added water to the iron and sand mixture, what happened to the iron? What property of iron allows you to separate it from sand in this way?
3. When you added hot water to sand and table salt, what was left in the pie pan? What property of salt enables you to separate it from sand in this way?

Conclusion

Why won't just one method work to separate these earth materials?

Step 6



Our Science Heritage

How Did We Learn to Use Metals?

Modern-day technology relies heavily upon the use of metals like iron, steel, copper, and aluminum. The use of metals, however, is not new. Scientists have found metal objects made by people thousands of years ago. Though no one knows for sure, the earliest use of metals probably dates back at least 8000 years.

A few metals are occasionally found alone in their natural state. Gold, silver, and copper are examples of such metals. Ancient peoples discovered that gold, copper, and silver could be shaped into a great variety of useful and beautiful objects. The oldest gold objects were made at least 5500 years ago.

Most metals are found in combination with other elements. Copper, for example, is usually found in copper ores. Iron and aluminum are found in ores, too. Ancient people probably discovered metals in ores by accident. Perhaps rocks containing copper or lead were heated in a fire. Afterward, small amounts of copper or lead might have been found among the rocks. Iron is not easy to separate from its ore because very high heat is needed. Nevertheless, it is estimated that people have been separating iron from its ores for at least the past 4000 years.

Ancient people also discovered that metals could be combined to form new metals. These new metals, called alloys, contain very useful physical properties. Bronze, which is an alloy of copper and tin, was first discovered about 5500 years ago and played a very important part in human development.

Many of the early uses of metals were made by trial and error. As scientists learned more about the nature of matter, much more was discovered about the use of metals. As the earth's supply of certain metals is used up, scientists must look to new metals to meet the needs of the world's population.

Beautiful bronze and gold work is characteristic of early Irish art. This bronze sword hilt is from the first century B.C.

from the earth. Sometimes it costs too much to remove the needed substance from the mineral or rock through a refining process. Sometimes it costs too much in terms of what removing the material does to the earth's surface.

The total cost of obtaining and refining ores is, therefore, influenced by several factors: 1) the cost of removing the ore

from the earth, 2) the cost of transporting the ore to a refinery, 3) the cost of refining the ore, 4) the cost involved because of the loss of the mined area for other purposes, especially where open-pit mining and strip mining are involved, and 5) the cost of restoring the mined area to something more closely resembling its original condition.

Check yourself

1. List physical properties of metals that distinguish them from nonmetals.
2. Describe how useful substances are obtained from rocks and minerals. Include the terms *ore, mining,* and *refining.*

Using fossil fuels

Where do all fossil fuels come from?

Plants and animals that lived and died long ago have been a source of very important products called **fossil fuels.** Fossil fuels are fuels that are brought up out of the earth. Three fossil fuels are petroleum (oil), natural gas, and coal.

Petroleum (puh-TRŌ′-lee-um) and **natural gas** are fossil fuels that are found in rock. Petroleum, whose name comes from the Greek words for rock and oil, is a liquid. Natural gas is a gas. Both petroleum and natural gas can occupy the tiny spaces between grains of sediment. Both can also fill pores and cracks in rocks. And both are frequently found next to each other.

Water is also able to penetrate nearly all pore spaces and cracks in rocks, even to great depths below the surface. Figure 2-24 shows areas of a porous rock layer whose pore spaces are saturated with water, petroleum, and natural gas. The rock layer containing the water, petroleum, and natural gas has been bent by some movement of the earth's crust. You will note, however, that the layers of pore spaces that are filled with water or petroleum or natural gas do not bend with the rock layer. Rather, the layers of water, petroleum, and natural gas tend to seek their own levels.

In Figure 2-24, the petroleum is located above the water be-

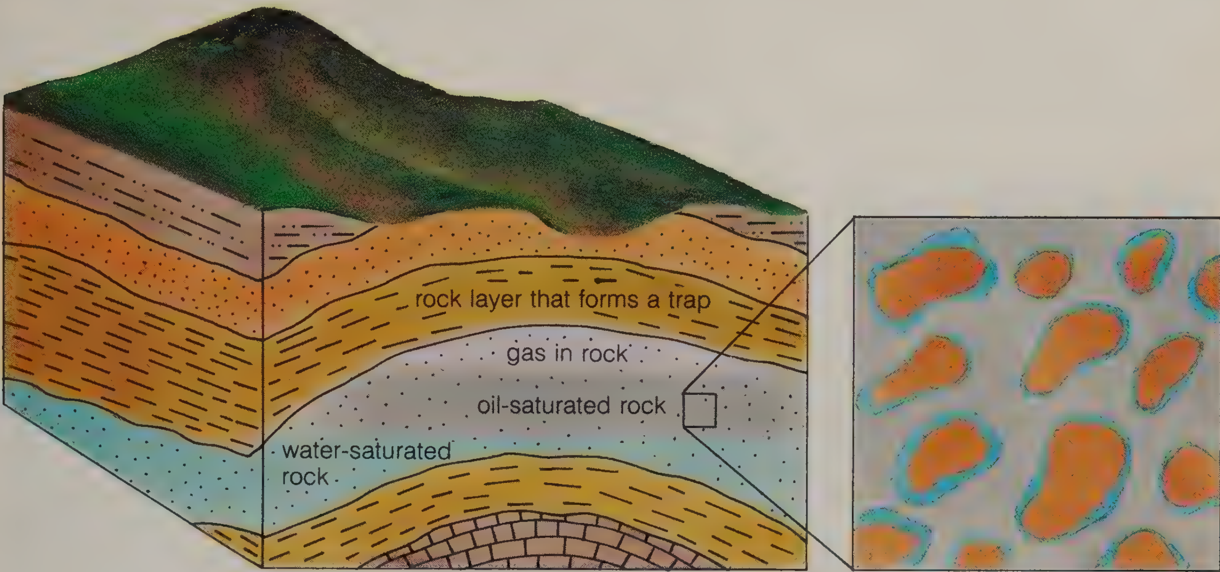


Figure 2-24. This cross section shows water, oil, and gas in some bent layers of solid rock. 1) How can water, oil, and natural gas be in solid rock? 2) Why don't the levels of water and oil bend with the rock layer?

cause petroleum tends to float on water, even underground. And the natural gas, the least dense of the three materials, is located above the petroleum. Petroleum and natural gas move slowly up through sediments and rocks until they are blocked by a material that is too solid to let them pass through. This kind of blockage is called a **trap.** A trap is what geologists look for when they explore for petroleum and natural gas.

No one knows for sure how petroleum and natural gas formed. The most common theory is that they formed from the remains of microscopic plants and animals that lived in the earth's oceans. As the plants and animals died, their remains accumulated on the bottom of the sea. Bacteria in the water caused the plant and animal remains to decay. At the same time, the decaying material was covered with sediment that washed into the sea from the land. Over a long period of time, the sediment piled up to great depths. This caused heat and pressure on the decayed material beneath the sediment. All four factors—time, heat, pressure, and decay by bacteria—may have changed the plant and animal remains into petroleum and natural gas.

Petroleum has more uses than just about any other substance on earth. From it are made many forms of fuel and lubricating oils. From it are also made hundreds of chemical products called **petrochemicals.** Petrochemicals are used to make fertilizers, insecticides, plastics, synthetic fibers, and many other products that are in wide use throughout the world.

Coal is a solid fossil fuel that is mined both at the surface and underground. Coal is thought to have formed from layers of

Library research

Make a list of the major petroleum producing areas in the world and the amount of known reserves. Find out what the world consumption rate of petroleum is now, and what it is expected to be in the future. Also, estimate how soon our known reserves could run out.

Figure 2-25. Parts of all of these products are made of plastic. How is plastic related to petroleum?

plant material, called peat, that became buried in a wet environment, failed to decay completely, and then changed through heat and pressure into coal.

In the formation of coal, the plant material passes through a number of stages. With each stage, the plant material increases in hardness and in heat value. Heat value is the amount of heat given off by a certain amount of fuel. As the peat becomes buried under successive layers of overlying material, heat and pressure change the peat, which is very soft, into lignite. Lignite is a soft coal that has a low heat value. Continued and increasing heat and pressure turn the lignite into a better grade of soft coal called bituminous coal. Finally, the great heat and pressure associated with deep burial produces a hard coal called anthracite coal, which has the highest heat value of the various forms of coal.

Coal has many uses. It can be processed to make artificial gas. It is burned to produce steam, which is then used to produce electrical power. It is used to make various chemical products. Also, bituminous coal is especially valuable because it can be changed into coke, a fuel used in making steel.

Check yourself

1. Describe how petroleum and natural gas become trapped beneath the earth's surface. In your description, include the terms *water, pore spaces, blockage,* and *trap.*
2. Describe how petroleum and natural gas may have formed.
3. Describe how coal is formed. In your description, include the terms *anthracite, heat value, heat,* and *pressure.*

Using the wind and the sun

The wind can be used to push a sailboat. The wind can also be used to turn the blades of a windmill. In both cases, people use the wind to do work for them.

People's use of the wind has played an important part in the development of the world as it is today. Up through the nineteenth century, sailing ships were the main means of carrying

Figure 2-26. By means of windmills, people can make the wind do work for them. What kinds of work can windmills do?

products and people over the oceans. And windmills have long been used to pump water from the ground and to grind the grain needed for flour. At present, windmills are also being used to generate electrical energy.

Energy from the sun, or **solar energy,** is obviously not an earth material. But earth materials are used to capture this energy and to store it for future use.

Solar energy can be used for heat. Energy from the sun is called radiation. Some of this radiation is called sunlight. Glass, a product of earth materials, can be used to trap radiation. Sunlight will pass through the glass and warm any objects that are behind the glass. As the objects warm up, they in turn radiate heat. This heat is trapped behind the glass because it will not pass through glass as sunlight will.

On a sunny day, a closed structure with a lot of glass will heat up rapidly. This is the way greenhouses keep warm from sun-

Figure 2-27. These solar panels are able to capture energy from the sun. Solar energy can be used for heating purposes. It can also be used to generate electricity.

light. Some people are able to heat their houses the same way, using the sun to heat water or rocks. The heat stored in the water or rocks can later be used to heat the house when the sun is not shining.

What do solar cells do?

Solar energy can also be used to generate electricity. Silicon and traces of a few other earth materials are used in making solar cells that change sunlight into electricity. Because solar cells are very expensive to make, electrical energy from solar cells costs much more to produce than electrical energy from other sources.

Check yourself

1. How has the wind been used to do work?
2. How are earth materials used to trap energy from the sun?

Using water

People have learned to use the earth's water as a source of energy. Two types of energy that depend on water are hydroelectric energy and geothermal energy.

Solar energy is powered by the sun. **Hydroelectric energy** is powered by both the sun and gravity. Because of the sun, water

reaches even the highest locations on the earth's surface. The sun causes water on the earth's surface to evaporate, changing from a liquid to a gas called water vapor. The water vapor passes into the atmosphere. Cooler temperatures high in the atmosphere cause this water vapor to condense, changing from a gas to a liquid or even to a solid such as snow or ice. This liquid or solid water then returns to the earth's surface.

Because of gravity, the water that falls from the atmosphere flows from higher to lower levels on the earth's surface. This flowing water, which is being pulled downward by gravity, can be directed into a channel. Once channeled, the flowing water can be used to turn the blades of a turbine. A water turbine is a modern version of a water wheel. As the turbine spins, it turns a generator that makes electricity.

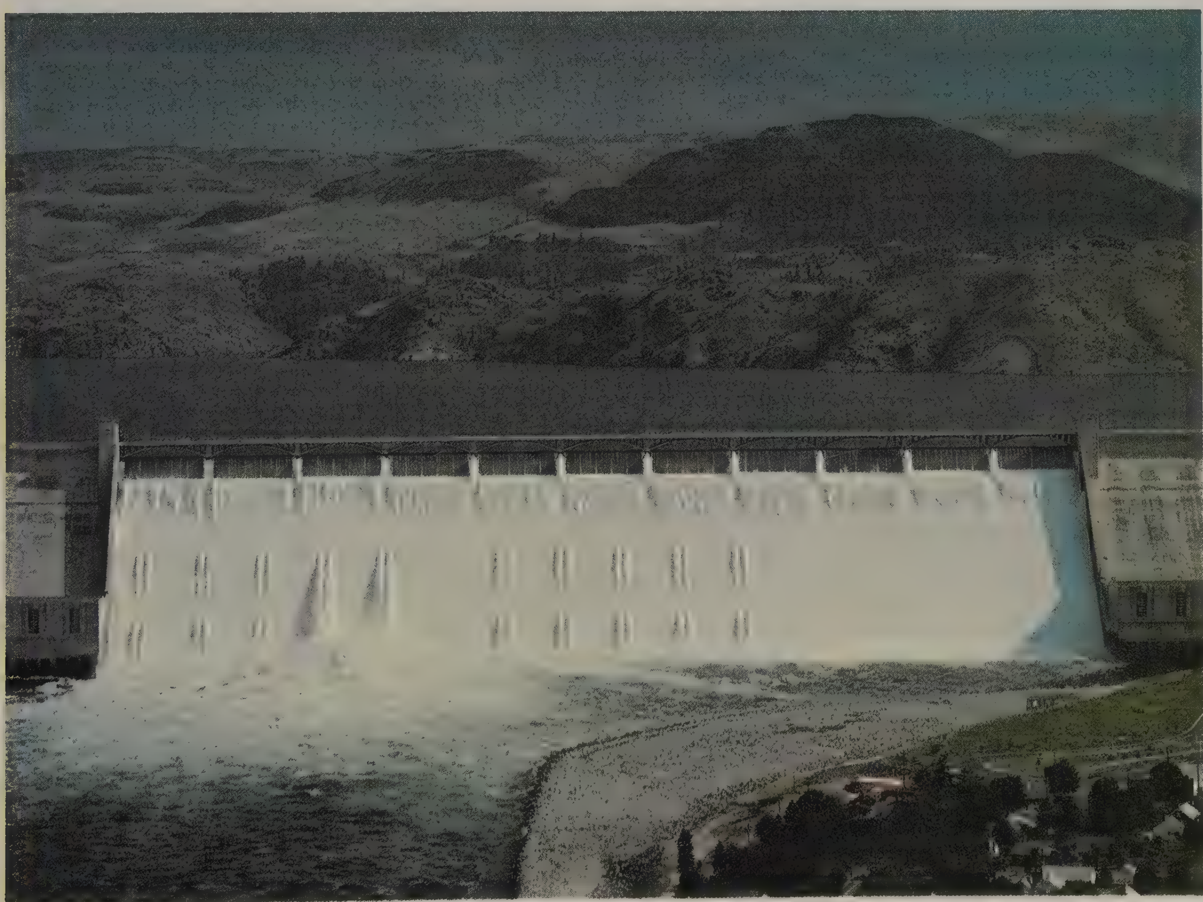


Figure 2-28. The Grand Coulee Dam across the Columbia River, Washington, is as high as a fifty-story building. How does solar energy replenish the supply of water behind the dam?

Figure 2-29. This geothermal power station is located in Wairakei, New Zealand. Where does the heat used in this power plant come from?

Can the rise and fall of the tides be used to generate hydroelectric energy?

Where does the heat within the earth's crust come from?

Most turbines and generators are built into dams across rivers. That way the water level will be very high behind the turbine. Also, the flow of water through the turbine will be constant all year long, even during times of little rainfall.

Hydroelectric energy is also generated by using the tides, which are the regular rise and fall of the level of the sea. A dam is built across the mouth of a bay. The rise and fall of the ocean water, powered by the moon's gravitational pull, causes a difference in water level on opposite sides of the dam. Letting the water through the dam spins the turbines.

Another type of energy that uses water is geothermal energy. **Geothermal energy** is powered by heat from deep within the earth's crust. This heat is believed to come from radioactive elements in minerals and from the friction of internal movements. The outer part of the earth's core may be molten, and this heat adds to the other heat sources.

The heat in the earth is high enough in some places to melt rock and form magma. In such places, any water will be in the form of steam, which can be brought to the earth's surface and used to turn the turbines of electrical generators.

If no water is present, two wells can be drilled down into the rock. Cold water can be forced down one well, heated by the rock, and brought back to the surface in the other well. In some places, the rocks at depth may not be hot enough to produce steam. Even so, the returning water from such wells is hot enough to heat buildings.

Check yourself

1. Describe how hydroelectric energy is produced. In your description, include the terms *sun, gravity, water, turbine,* and *generator.*
2. Describe geothermal energy, how it is obtained, and how it can be used.

Using atoms

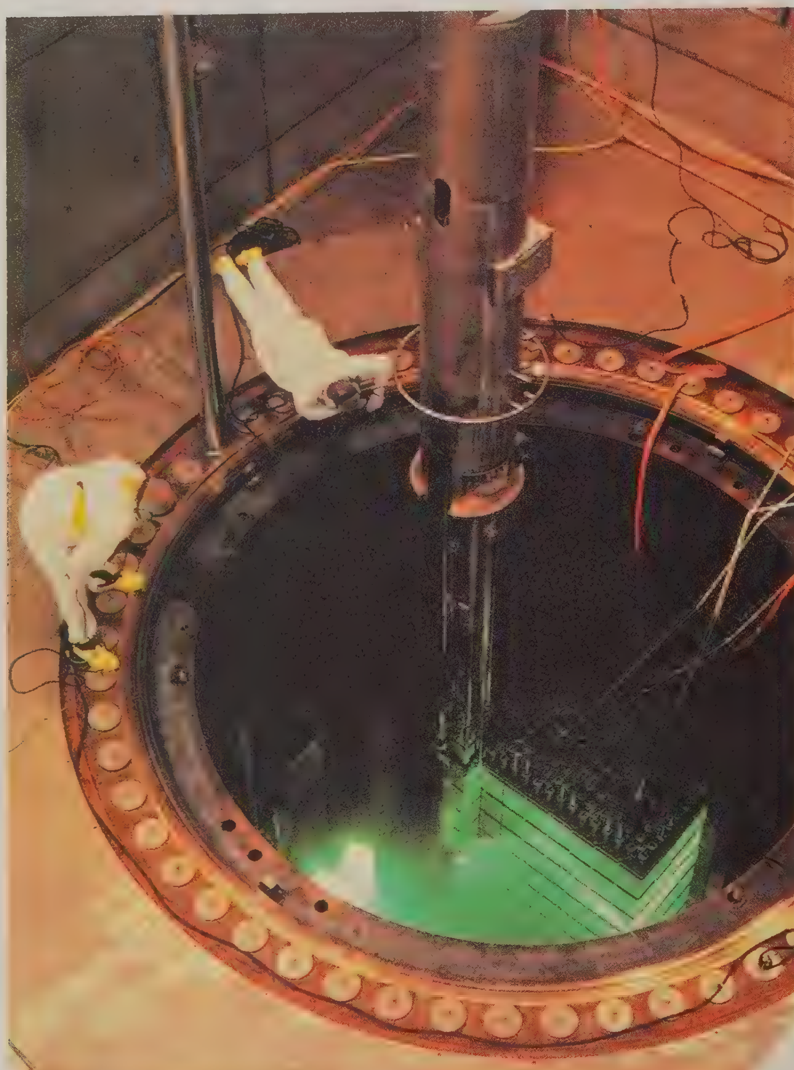
Atomic energy is energy that is derived from the atoms of certain earth materials. Because this type of energy involves the nucleus, or central part, of the atom, it is also known as nuclear energy.

One way of getting nuclear energy is called **fission.** The word *fission* comes from a Latin word that means to split apart. In nuclear fission, part of the nucleus of an atom is split away. During this splitting of the atom, heat energy is released and the atom is changed from one element into another element. The tremendous amounts of heat released are used to heat water. The hot water is then used to turn the turbines of electrical generators.

What are radioactive atoms?

Nuclear fission occurs when certain large, unstable atoms are made to split apart. These large, unstable atoms are said to be radioactive. Radioactive atoms are atoms that are gradually breaking down. As they do, they give off energy and tiny nuclear particles.

Figure 2-30. This photograph was taken at the San Onofre nuclear-powered generating plant near San Clemente, California. What are two ways of obtaining energy from the nucleus of an atom?



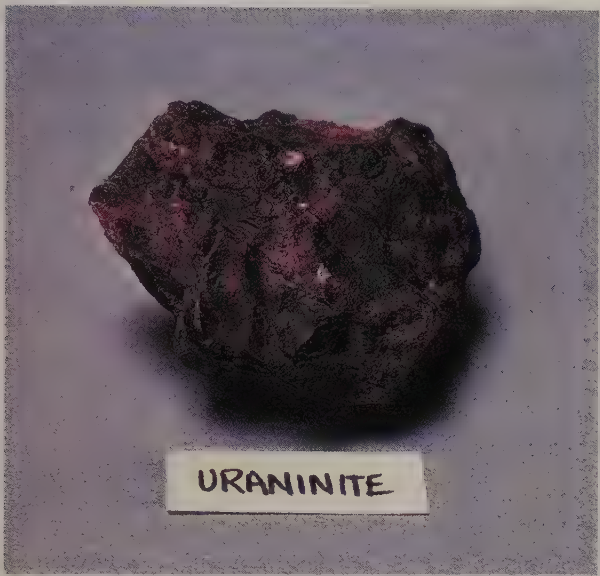
Library research

Using library sources, make a list of all the different types of ways we generate electrical energy. Make a list showing the relative ranking of which methods are used most, second most, etc. Indicate the earth material that is used to produce the energy for each type of electrical power.

Does plutonium occur naturally?

Some elements containing radioactive atoms occur naturally in the earth's crust. These produce much of the heat within the earth. One of these elements is uranium, which is found in several minerals. Uranium and plutonium, another radioactive substance, are commonly used for producing nuclear fission. Plutonium is not found in nature, but it can be produced in a laboratory from certain uranium atoms.

Another type of nuclear reaction involves **fusion.** The word *fusion* means fused together or joined together in some way. In



nuclear fusion, atoms of an element are fused together to form atoms of a different element, one with greater mass. Forms of the element hydrogen are commonly used in nuclear fusion research. The fusion of atoms of hydrogen, which has the least mass of any element, requires less heat and pressure than the fusion of atoms of elements with greater mass.

Figure 2-31. Uraninite (pitchblende) and carnotite are uranium ores. How is uranium related to nuclear energy?

Nuclear fusion generates great amounts of heat, but it occurs only under extremely high temperature and pressure. Nuclear fusion occurs naturally in the sun and the stars. The pull of gravity in the sun and the stars creates enough pressure and heat to produce a fusion reaction. The light and heat that the earth receives from the sun are the result of a nuclear fusion reaction on the sun.

As with any of the other forms of energy, there are problems connected with the use of nuclear reactions. In the case of nuclear fission, there is the problem of radioactivity, which is harmful to living things. In nuclear fission, radioactivity is involved both during the reaction and in the radioactive wastes that are produced. In the case of nuclear fusion, there is the problem of control. Scientists have not yet been able to create a controlled nuclear fusion reaction from which electrical energy can be generated. But if they do succeed, nuclear power generation should become much less of an environmental

What is preventing nuclear fusion from being used as a source of electrical energy?

Careers Petroleum Geologist / Technical Secretary

A petroleum geologist uses a microscope in the laboratory to analyze rock samples taken in the field.

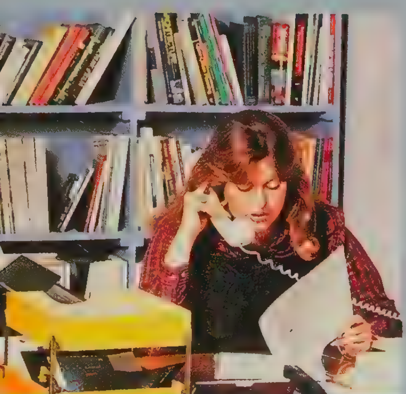
Petroleum Geologist
Petroleum geologists participate in different activities—some in the field and some in the laboratory. The primary purpose of this profession is to explore and interpret the earth's crust in an attempt to discover more petroleum.

Some of the work involves interpretation of the earth's crystal rocks and structures. Many techniques are used—for example, field mapping, working with photographs taken from airplanes, working with information transmitted from satellites, and using sophisticated electronics equipment to gather data in the field.

Exploratory wells are drilled in likely looking areas, and the geologist interprets the rock samples from the different depths in the wells. The samples are analyzed for their age, fossil content, rock type, and possible relationship to other rocks in the area. Much of the analysis of the fieldwork and exploratory drilling is done in laboratories.

The geologist uses a range of techniques and equipment, from simple rock crushers to elaborate computers and electron microscopes.

Petroleum geologists usually work for oil companies. Most of the petroleum geologists have a geology degree from a college. Many petroleum geologists continue schooling and complete one or more graduate degrees.



A technical secretary provides invaluable assistance to engineers and scientists.

Technical Secretary If working in an office appeals to you, you might like to become a secretary. Secretaries are responsible for the smooth running of an office. They answer phones, type letters and reports, keep accurate files, and make needed arrangements.

If science appeals to you, you might like to become a technical secretary. Technical secretaries work for and assist engineers and scientists. In addition to the smooth running of the office, a technical secretary may be responsible for writing routine correspondence, gathering and editing materials for scientific papers, or maintaining a technical library.

To become a technical secretary, you should learn office skills such as typing and word processing. You should also study English and science.

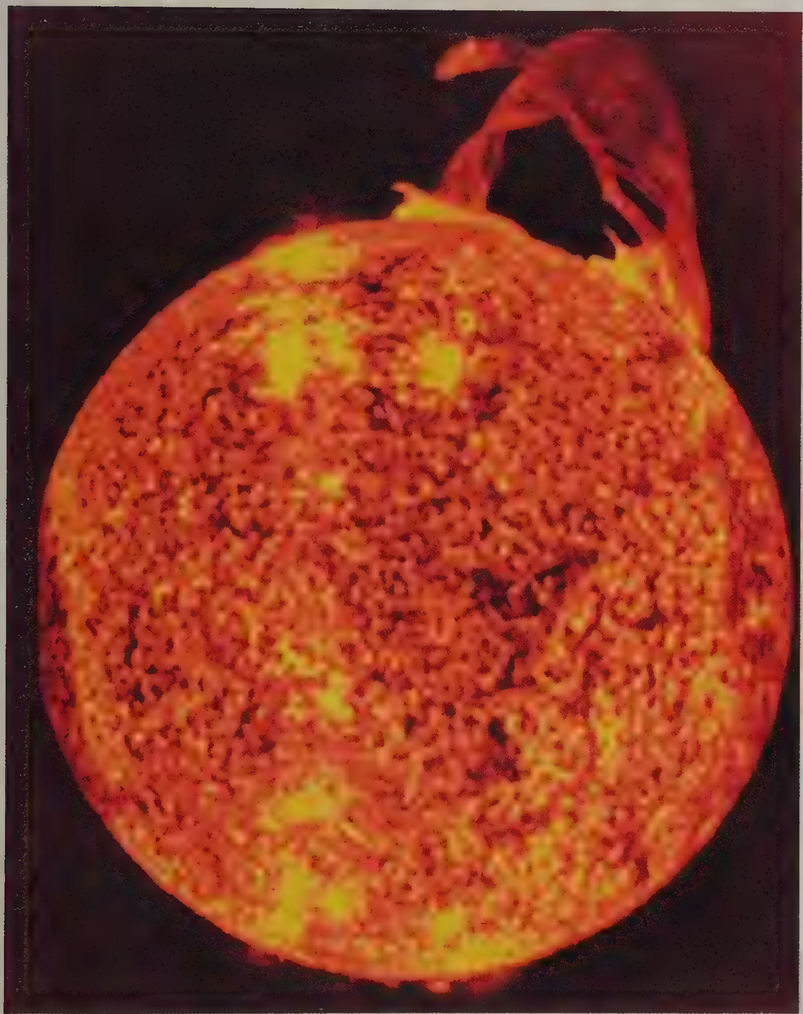


Figure 2-32. This photograph of the sun was taken December 19, 1973, by NASA's *Skylab 4*. It shows one of the most spectacular solar flares ever recorded, spanning more than 588 000 km (367 000 mi) across the surface of the sun.

hazard because fusion reactions produce very little radioactive waste material. The problem can, indeed, be compared to that of harnessing a piece of a star on earth.

Check yourself

1. Distinguish between the process of nuclear fission and the process of nuclear fusion.
2. Describe the problems connected with using nuclear fission and nuclear fusion as sources of energy.

Activity Simulating Ore Reserves and World Demand

Materials

clock or watch that indicates seconds

152 pennies per group

Purpose

To learn about the supply of and demand for the world's metal ores.

What to Do

Before you begin, read all of the following steps. Make sure you understand what you are to do.

1. Each person in a group assumes one of these roles:
   Ore Reserves Nature World Demand
2. Ore Reserves forms a pile of 120 pennies.
   This pile stands for the copper ore reserves that nature built up before people started to mine copper ores.
3. Nature forms a pile of 32 pennies.
   This pile contains the amount of copper that will be concentrated to form new copper ores during the game.
4. Begin the game when the indicator on your watch or clock passes the 60-second mark.
5. Fifteen seconds after the game has begun, Nature adds a penny to Ore Reserves' pile. Every 15 seconds for the rest of the game, Nature adds another penny to that pile.
   This stands for the constant rate at which copper is concentrated into new ores in the real world.
6. At the end of the first minute of the game, World Demand removes a penny from Ore Reserves' pile. At the end of each succeeding minute, World Demand doubles its demand. At the end of the second minute, it removes two pennies; at the end of the third minute, four pennies; then eight, and so forth.
   This stands for the real situation in which increasing nnumbers of people put ever greater demands on the earth's supply of copper.
7. Continue to play until Ore Reserves can no longer meet the demands of World Demand.
8. Note how long it took for World Demand to remove all the pennies from Ore Reserves.
9. Record what happened in a chart that begins like the one on this page. The first two minutes of play have already been recorded. Complete the chart for the entire game.

Questions

1. What is the greatest Total in Ore Reserves (column E of your chart)?
2. Why does the Total in Ore Reserves (column E) decrease rapidly after four minutes?
3. During which minute of time elapsed does the Subtotal in Ore Reserves (column C) become too small to meet the output demanded by World Demand (column D)?

Conclusion

How does supply and demand affect world requirements for metal ores?

	A	B	C	D	E
Number of Minutes Elapsed	Total in Ore Reserves (E) at Beginning of Each Minute	Input from Nature (4 per minute)	Subtotal in Ore Reserves (A + B)	Output to World Demand	Total in Ore Reserves at End of Each Minute
1	120	+4	124	−1	123
2	123	+4	127	−2	125

Section 3 Review Chapter 2

Check Your Vocabulary

atomic energy	mine
coal	natural gas
fission	ore
fossil fuels	petrochemicals
fusion	petroleum
geothermal energy	solar energy
hydroelectric energy	trap

Match each term above with the numbered phrase that best describes it.

1. Any mineral or rock from which a needed substance can be removed cheaply enough and easily enough
2. The place that ore comes from
3. Fuels formed from the remains of plants and animals that lived and died long ago
4. A liquid fossil fuel
5. A fossil fuel that is a gas
6. A kind of blockage formed by nonporous rock that traps petroleum and natural gas
7. Chemical products made from petroleum
8. A solid fossil fuel
9. Energy from the sun
10. Electricity produced by generators powered by moving water
11. Energy powered by heat from deep within the earth's crust
12. Energy derived from the atoms of certain earth materials; also called nuclear energy
13. Atomic energy that is produced when certain large, unstable atoms are made to split apart to form atoms of a different element
14. Atomic energy that is produced when atoms of an element are fused together to form atoms of a different element

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Steel, copper, and aluminum are examples of _?_.
   a) phosphates c) metals
   b) nonmetals d) nitrates
2. Petroleum, natural gas, and water travel through _?_.
   a) lava c) nonporous rock
   b) porous rock d) no rock at all
3. Natural gas and _?_ are frequently found next to each other.
   a) petroleum c) coal
   b) lignite d) petrochemicals
4. _?_ can change sunlight into electricity.
   a) Greenhouses c) Tides
   b) Gravity d) Solar cells
5. The light and heat that the earth receives from the sun is the result of _?_.
   a) nuclear fusion c) geothermal energy
   b) nuclear fission d) hydroelectric energy

Check Your Understanding

1. Describe properties of metals that make them important.
2. Give five important uses of nonmetals.
3. Describe the kind of trap that geologists look for when they explore for petroleum and natural gas.
4. Describe how hydroelectric power is obtained. Include the types of construction and machines needed.
5. Describe what happens when an atom is split.

Chapter 2 Review

Concept Summary

Matter is anything that occupies space and has mass.

- ☐ Matter is considered to be made up of atoms (the smallest complete part of an element).
- ☐ An element is a substance that contains only one kind of atom.
- ☐ A compound is a substance that is made up of two or more elements.

Minerals are naturally occurring, inorganic, and crystalline solids.

- ☐ Minerals are grouped into large classes on the basis of their key elements.
- ☐ Minerals are identified on the basis of their physical properties.
- ☐ Though all minerals are crystalline solids, not all minerals have the freedom to grow into visible crystals.

Most **rocks** are combinations of two or more minerals.

- ☐ Rocks are classified into general types by the way in which they form.
- ☐ Rocks are identified by their texture and mineral composition.
- ☐ Earth processes are continually changing rocks from one type to another.

Earth materials consist of all the matter found on the earth.

- ☐ Earth materials include rocks, minerals, fossil fuels, and water.
- ☐ Nearly everything people use was made either from or by earth materials.
- ☐ The cost of using earth materials involves more than the cost of obtaining and processing the material; it also involves restoration costs and/or loss of materials and landscape.
- ☐ Energy can be produced from such earth materials as radioactive minerals, fossil fuels, and water.
- ☐ Solar energy and wind energy are captured by using earth materials.

Putting It All Together

1. What information would a person need to distinguish a mineral from a nonmineral?
2. Explain how differences in the physical properties of minerals are related to differences in the basic blocks of the minerals.
3. Let's say that you find a mineral sample but are not sure which mineral it is. Describe what you would do to determine the mineral in your sample.
4. Draw a diagram of a building. Label various earth materials (metals and nonmetals) used in the building.
5. Make three lists of rocks, one for each general class of rocks you have studied, that contain silicate minerals. Label each list: Igneous (or Sedimentary or Metamorphic) rocks that contain silicate minerals. What silicate minerals are in the rocks in each list?
6. What are some of the different types of rocks that nonsilicate minerals form?
7. What are the basic differences between identifying minerals and identifying rocks?
8. Describe how a metamorphic rock can be changed into a different metamorphic rock. Give an example.
9. What are the relative merits and drawbacks of the different types of atomic energy?
10. Describe some of the variables that would make the difference for a mineral deposit to be an ore or not to be an ore.

Apply Your Knowledge

1. What properties of a mineral would tend to make it valuable as a gemstone?
2. Describe how texture can be a clue to the history of a rock's formation.
3. In an igneous rock, what is the relationship between crystal size and rate of cooling of the molten material?

4. Describe the processes and environments that could result in the following changes of rock types: granite → sandstone → gneiss → granite.
5. Which types of building stone would weather fastest from acid rainfall?

Find Out on Your Own

1. Visit the nearest locality or localities where minerals can be collected. Collect several specimens. For each specimen, 1) identify the mineral, 2) specify where it was found, 3) name the person who found the specimen, and 4) list the date on which the specimen was found.
2. Using the techniques and properties you have learned, make a detailed list of each of the minerals in your collection.
3. Determine the different types of rocks that are used locally in public buildings or cemeteries.
4. If an oil company were to drill a well in your community, what sequence of rocks would they find beneath the ground? Which of these rocks might be a good reservoir for oil?
5. What types of minerals and rocks are mined within a 75 to 150 km radius of your home? Determine how this material is processed and used.

Reading Further

Bramwell, Martyn. *Understanding and Collecting Rocks and Fossils.* Tulsa, OK: Educational Development Corp., 1983.

An easy-to-use guide to finding and identifying the most common rocks, minerals, and fossils. Also contains interesting experiments as well as a fine description of how rocks are formed.

Branley, Franklyn M. *Feast or Famine? The Energy Future.* New York: Crowell, 1980.

Contains a wealth of information on the uses, sources, and forms of energy. Assesses various energy options.

Chesterman, Charles W. *The Audubon Society Field Guide to North American Rocks and Minerals.* New York: Alfred A. Knopf, Inc., 1978.

An easy-to-use field guide that will interest both the beginner and the experienced rock hound. Beautiful photographs that show clearly the physical properties of hundreds of different rock and mineral specimens.

Deudney, Daniel, and Christopher Flavin. *Renewable Energy: The Power to Choose.* A Worldwatch Institute Book. New York: Norton, 1983.

Surveys renewable energy technology. Moderately short and very readable. Provides up-to-date coverage of a fascinating subject without burdening the reader with nonessential detail.

Leon, George de Lucenay. *Energy Forever:* Power for Today and Tomorrow. New York: Arco Publishing, Inc., 1982.

Presents a definition of what energy is and discusses the various renewable and nonrenewable sources which can provide us with the energy we need in the future.

Pough, Frederick H. *A Field Guide to Rocks and Minerals*. Boston: Houghton Mifflin, 1976.

Part of the popular Peterson Field Guide Series. A handy reference book that will answer just about any question you have about a rock or mineral.

Satchwell, John. *Energy at Work.* New York: Lothrop, Lee and Shepard, 1981.

An extremely enjoyable book on the world energy crisis and suggestions for conservation. Difficult concepts are made easy to understand. Highly recommended.

Science Issues of Today The Search for Earth Materials

Copper, iron, zinc, tin, lead, aluminum, silver, gold, molybdenum, platinum, uranium, vanadium, titanium, and mercury are only a few of the elements obtained from rocks and minerals that are extremely important in maintaining an industrialized society. All of these elements are being mined in different parts of the world. Mining is a process that takes from nature faster than nature can replenish the earth. The more people mine these elements, the less that remains for future use.

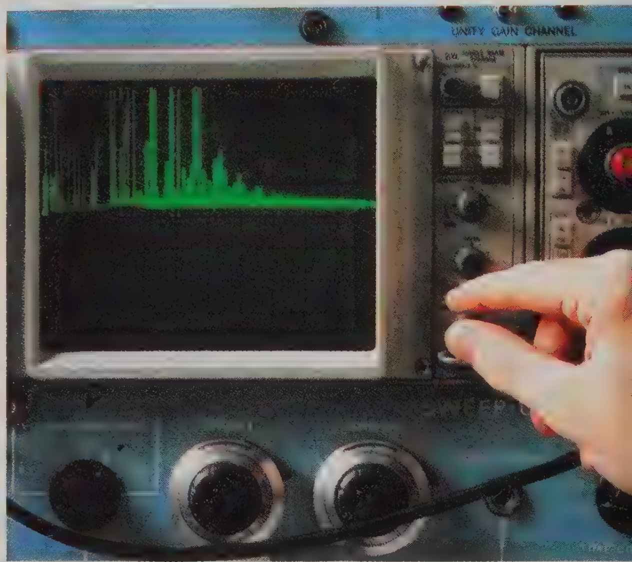
In the early history of mining, the search for minerals was limited to looking at surface deposits that were easily seen. The deposits that were mined contained minerals extremely rich in the desired elements; these minerals had a composition that made extraction of the elements relatively simple. These easily found surface deposits have essentially been mined out so that it has become harder to find minable minerals.

The modern geologist uses many tools in searching for mineral deposits. Some of the simplest tools include topographic and geologic maps. Surface shapes and distribution of rocks are sometimes clues to what might be found beneath the earth's surface. But they are only clues, and to verify the subsurface deposits the geologist has a multitude of investigative techniques using modern technology.

Seismic exploration uses the returning echos from artificial shock waves to determine the shapes of rock masses and layers beneath the surface.

Magnetic surveys measure variations in magnetic intensity and may help to locate specific rock types or iron ore deposits.

Gravity surveys allow geologists to map very slight variations in the pull of gravity. These variations can be caused by differences in the density or specific gravity of different rock types.



Peaks in a spectograph display help researchers identify the different elements in a prepared sample. Different elements will form peaks at different places across the screen.

Aerial photographs and satellite imagery show large scale structural features that may be undetectable by a mapping team on the ground.

Analysis of solutions obtained from sediments and plants with an Atomic Absorption Spectrophotometer will often show very tiny amounts of elements that may indicate a nearby source for those elements.

Most successful exploration programs use several or all of the above techniques. As technology changes, so does our ability to discover new, economically valuable mineral resources.

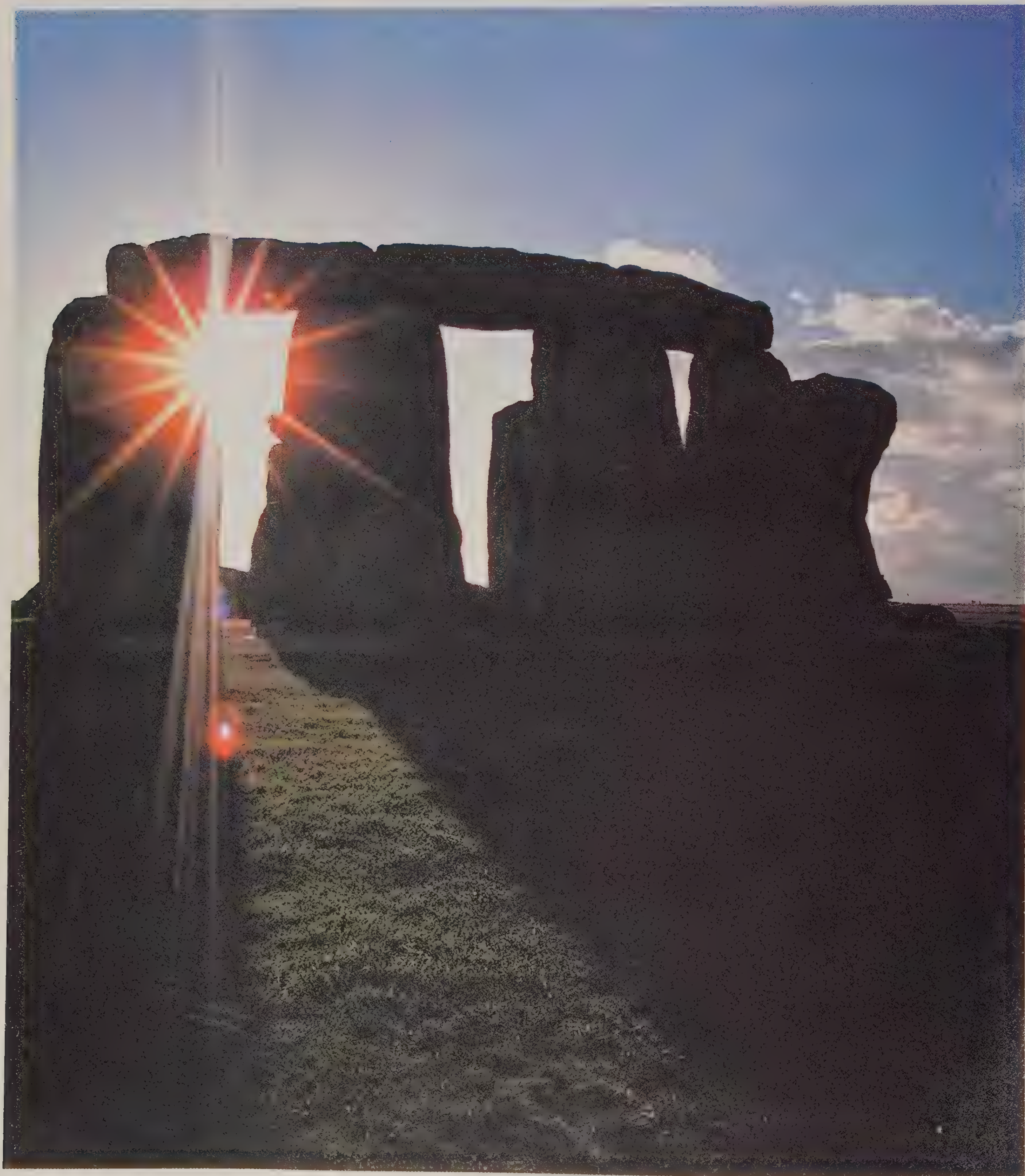
The Earth in Space

Unit 2

The physical earth can be considered as an object in itself. The matter that makes up the earth can be considered in isolation. But certain earth processes and certain observable changes can be explained most easily when the earth is considered as a planet in motion around the sun.

Think of all the objects that appear to move across the sky. The sun and moon appear to rise and set. Winds blow. Rain and snow fall from the sky. Seasons change. Night falls. Climates vary from one place to another. Something is in motion—either the earth, or the objects other than the earth, or maybe even everything is in motion. Scientific advancement throughout recent history has enabled us to formulate a clearer description of the earth as a planet in a solar system in space.

Chapter 3



Earth Motions

Section 1
Observing the Night Sky

Motion is detected by a change in the relative positions of two or more objects. By observing objects that are at some distance from the earth, it is evident that the relative position of the earth changes with respect to these objects. The stars and planets of the night sky have long been admired for their beauty. They do not, however, always appear to be in the same place in the night sky. Something, therefore, is moving—either the objects in the night sky or the earth, or maybe even both.

Section 2
The Earth Rotates

Another object at some distance from the earth is the sun. And the sun's position changes, depending upon the time of day. Because of this change in the relative positions of the sun and any particular location on the earth's surface, we know that something is moving—either the sun or the earth, or maybe even both.

Section 3
The Earth Revolves

Changes in the relative positions of the earth and objects in the sky can be explained by not one but two earth motions. One earth motion explains daily changes (like morning, noon, and night). Another earth motion explains yearly changes (like the seasons). In this second earth motion, the earth is a satellite that revolves around the sun once a year. At the same time, the earth's natural satellite (the moon) and its artificial satellites are continually revolving around the earth.

Stonehenge, pictured on the facing page, is an ancient monument in England. It is believed to be a form of calendar that was based on regular changes in the sky. In this chapter, you will see how certain changes in the sky can be explained by means of earth motions.

Observing the Night Sky Section 1

Section 1 of Chapter 3 is divided into four parts:

Models of the night sky

Locating some constellations

Azimuth and altitude

Observations of motion

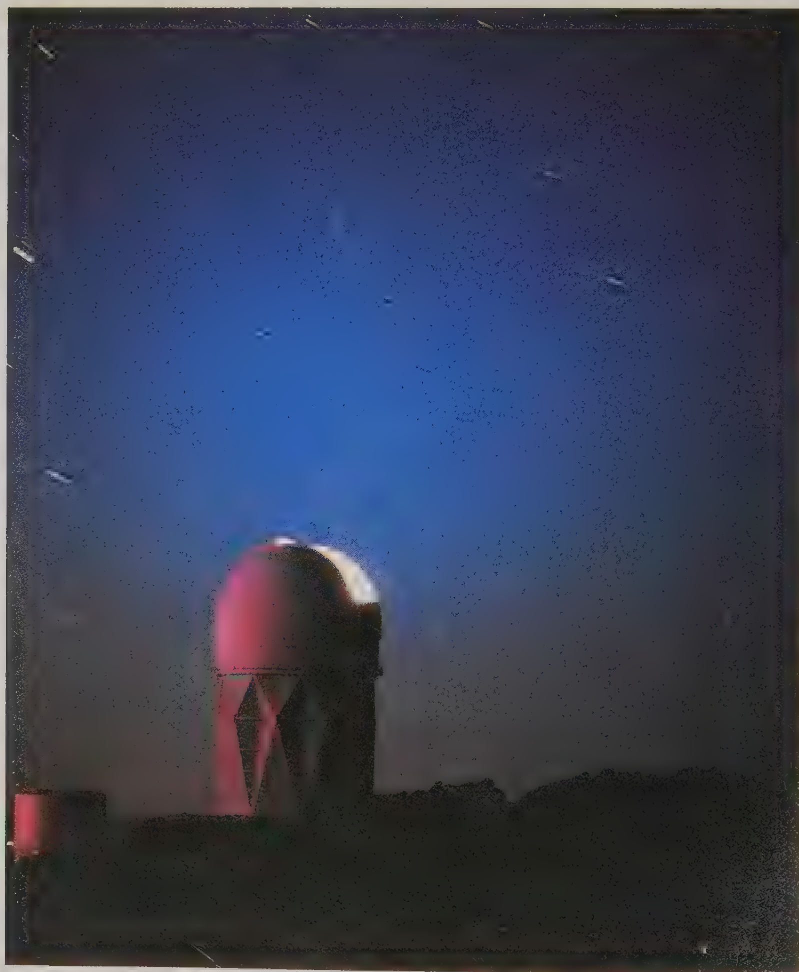


Figure 3-1. Within an observatory is a telescope that is used to observe stars and planets. The roof of the observatory is dome-shaped and revolves so that, when a portion of the roof is opened, the telescope within the observatory can be pointed toward any star in the sky. When you look at the sky, what shape does it appear to have?

Imagine that you are at a planetarium. You are sitting in the planetarium theater, in a high-backed chair that is tilted back so you can see the ceiling. The dome-shaped ceiling, which is fully lit at the moment, is like the inside of half a globe. On the floor in the middle of the room is a very strange-looking piece of machinery. It is the planetarium projector and is used to project the sun, moon, stars, and planets onto the ceiling of the theater.

As the show begins, the lights in the room gradually dim. Sunset comes to the ceiling on the inside of this special theater. As darkness descends on the room, stars and planets appear on the ceiling above you. You feel as if you are out in the middle of a field on a clear, dark night. By means of a pointer, the director of the show locates many of the objects that you may have heard are visible in the night sky where you live.

That same night, you look out your window at the night sky. You want to see if you can recognize anything that you saw on the ceiling of the planetarium. How do they compare—the planetarium and the night sky? How can you locate objects in the night sky? How can you describe the location of objects you see in the night sky? In this section of Chapter 3, you will learn the answers to these and other questions about the night sky.

In a planetarium theater, it is possible to represent the night sky as it will appear over your home tonight or as it appeared to the ancient Egyptians thousands of years ago. How do the objects of the night sky get onto the ceiling of the theater?

Figure 3-2. All objects on the celestial sphere appear to be the same distance from an observer. Are the objects in the sky really the same distance from an observer?

Models of the night sky

An obvious point of comparison between the night sky and the ceiling of a planetarium is the shape. The ceiling of a planetarium is shaped like a dome. The night sky looks like a huge dome that touches down all around the **horizon** (huh-RĪ′-zun), which is where the earth and the sky appear to meet.

The sky only looks like a dome. It really isn't. When you look up into the sky, you are really looking out into endless space. And the nighttime stars are not located on a dome. They are really located at many different distances from the earth. But the idea of a dome provides a useful way of studying objects in the sky. If you extend the dome of the sky so that it circles the entire earth, you produce a sphere. This imaginary sphere, on which all objects in the sky appear, is called the **celestial sphere** (suh-LES′-chul SFIR).

Figure 3-3. A celestial globe is the best model of the night sky. To read a celestial globe, where must observers imagine themselves to be?

Because the earth is round, a globe is the best model. Because the night sky appears to be dome-shaped, a star globe is the best model. But with a star globe, you have to imagine yourself looking at the surface of the globe from inside the center of the star globe. Other models of the night sky, which you may be more familiar with, include star maps and charts.

Check yourself

1. Why is a star globe the best model of the night sky?
2. What is the celestial sphere?

Our Science Heritage

How Are Astronomy and Astrology Related?

Modern astronomy is the scientific study of objects in space. But it has its roots in something that many people think is not scientific—the field of astrology. Many of the early discoveries in astronomy were made by astrologers. Ancient astrologers studied the positions of the various planets, thinking that the positions of these objects in space had an influence on people and events. Astrologers believe, for example, that an analysis of the position of the planets when a person is born will indicate the person's potential talents and personality traits.

The astrology we know today originated in Babylonia around 1000 B.C. It was very popular in ancient Greece. It was also popular in Europe throughout the Middle Ages. Astrology was so popular that many ancient astronomers became astrologers in order to support themselves. One of these ancient astronomer-astrologers was Ptolemy, who described the apparent motions of the planets. Others included Tycho Brahe and Johannes Kepler. You can, if you like, read about their accomplishments in any encyclopedia.

Modern astronomy has broken away from astrology. Most astronomers feel that there is very little evidence to support the claims of astrologers. Yet, astrology is still a popular pastime. Some people take it very seriously, while others look to it for amusement.

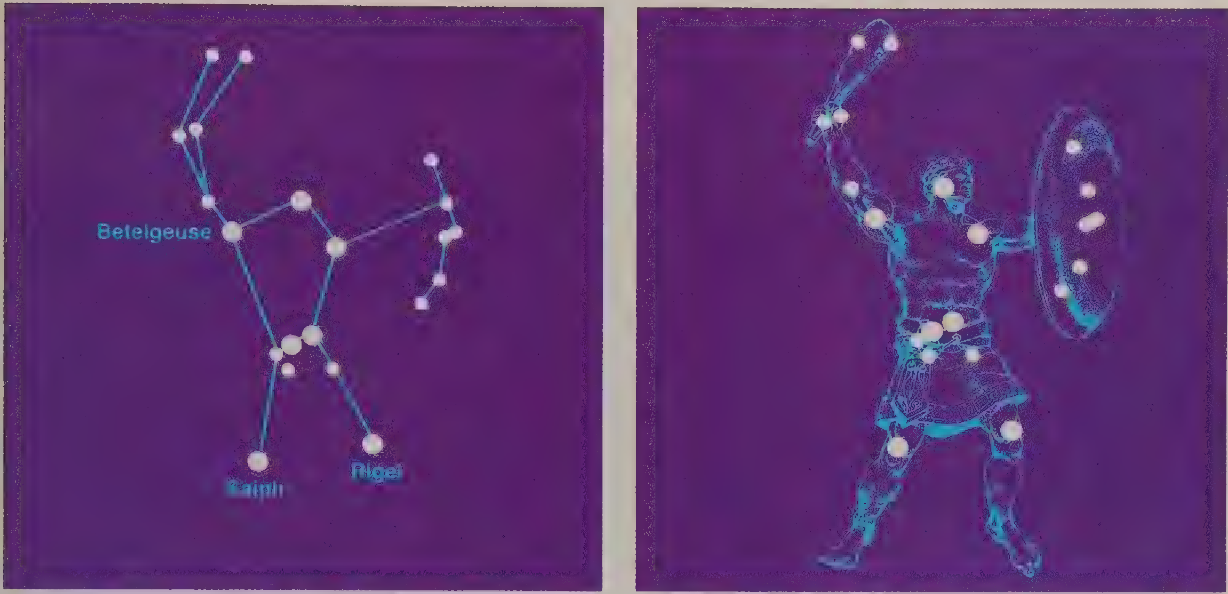


Figure 3-4. One representation of the constellation Orion the Hunter shows a hunter carrying a shield. What is a constellation?

Locating some constellations

In ancient times, people looked at the night sky and imagined that groups of stars formed outlines of people and animals. These groups of stars are called **constellations** (kon′-stuh-LAY′-shunz). The names that were given to the different constellations by the early observers are still used today.

If you were to look for the different constellations, you would probably have a difficult time finding some of them or picturing what they represent. But there are some constellations that are easy to find in the night sky. One such constellation is Orion the Hunter, shown in Figure 3-4.

Orion is the most spectacular of all the constellations because it contains many bright stars. The most striking part of Orion is his belt, which is made up of three bright stars that are close together in a straight line. Once you learn to recognize Orion's belt, you should have no trouble finding Orion among the many stars of the night sky. Orion can be seen in the early evening during the winter months. Seven or eight o'clock at night is a good time to look.

Also located in the constellation Orion are two very bright stars named Rigel (RĪ′-jul) and Betelgeuse (BET′-ul-jooz). Betelgeuse marks one of Orion's shoulders. Rigel can be thought to mark one of Orion's knees or feet. Find Rigel and Betelgeuse on the star map in Figure 3-5.

Rigel, Betelgeuse, and the stars in Orion's belt can be used to find other stars and constellations. Using the star map in

Figure 3-5. How can stars in Orion be used to locate other stars and constellations?

Figure 3-5, follow in a straight line from Rigel through Betelgeuse. This line will lead to the constellation Gemini, or the Twins. Two very bright stars named Castor and Pollux are located in the constellation Gemini.

Now find the stars of Orion's belt on the star map in Figure 3-5. A straight line passing through those stars and extending down below Orion's feet leads to a very bright star called Sirius (SIR′-ee-us). This star is part of the constellation Canis Major, which is Latin for "big dog." The star Sirius is the eye of the dog. For that reason, Sirius is often called the Dog Star. (Sirius is also the brightest star in the night sky.) A line passing through Orion's belt and extending upward past his shoulders leads to the constellation Taurus the Bull.

Figure 3-6 shows a group of stars that are easy to recognize. They form what is called the Big Dipper. The Big Dipper is part of the constellation Ursa Major, or the Big Bear.

Stars in one constellation can lead you to stars in another constellation. With the help of star maps, you can become fa-

Library research

Prepare a report on five constellations. Find out how they got their name. Then write a short history of the individual or animal that each represents.

miliar with the more common constellations. Little by little you will learn to find your way around the stars and constellations of the night sky.

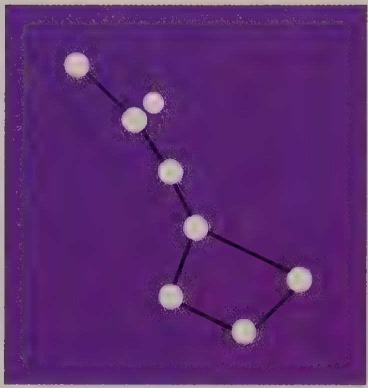


Figure 3-6. What constellation is the Big Dipper a part of?

Check yourself

1. Draw a simple diagram of the constellation Orion. Show how Rigel and Betelgeuse can be used to find the location of the constellation Gemini.
2. Draw a diagram of Orion. Show how the stars in the belt can be used to locate Sirius, part of the constellation Canis Major. Show how those same stars can also be used to locate Taurus the Bull.

Azimuth and altitude

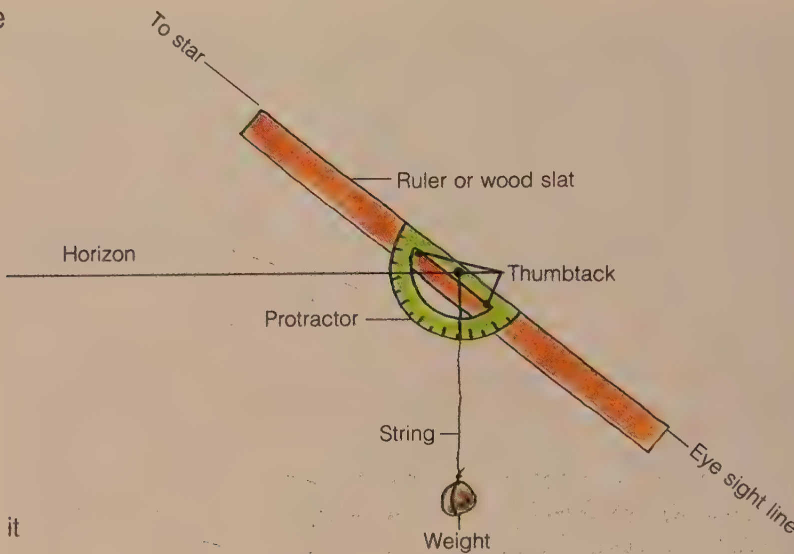
Let's suppose you are standing outside at night with a friend. How would you explain to your friend how to find a particular star or constellation that you know about? One way would be to point and hope that your friend can find the same star that you have in mind. Another way would be to use a landmark or object on the horizon. You might, for example, say, "Follow the chimney of that house straight up until you come to four stars that make a square." Your friend may or may not find the star(s) that you mean. Can you think of a more accurate way to locate an object in the sky?

As you may recall, any object on the earth's surface can be located in terms of its latitude and longitude. If its latitude is 70° S, you know that it is located somewhere along an imaginary line that circles the earth 70° south of the equator. If its longitude is 30° W, you know that it is located somewhere along an imaginary north-south line that is 30° west of the prime meridian. An object at latitude 70° S and longitude 30° W would be located where the two imaginary lines cross.

What is the connection between latitude, longitude, and locating a star on the celestial sphere?

A similar method can be used to locate a star on the celestial sphere. To do this, two measurements are needed. One measurement gives the altitude of the star. The **altitude** (AL′-tuh-

Activity Using an Astrolabe



Materials

weight
rule or wood slat
string
3 thumbtacks
protractor
paper and pencil or pen

Purpose

To construct an astrolabe and use it to measure the altitude of objects.

What to Do

1. Examine the diagram on this page and construct your own astrolabe. (Attach the weight, on a string, and the protractor to the rule with a thumbtack.)
2. With a partner, practice measuring the altitude of some objects in the room. Begin by pointing the sighting edge of the stick directly at the horizon. Let your partner read the angle (read where the string cuts across the protractor). Record your reading.
3. Point the sighting edge to a point directly above you. Record the angle.
4. Standing in the same place, measure the altitude of two or three other objects in the room—perhaps a light on the ceiling or a wall clock. Record your readings.
5. Standing in the same spot you've been measuring from, measure the altitude of the point where the ceiling and wall meet. Record your reading. Take four steps closer to the wall and sight again. Record this reading.
6. Let your partner repeat what you have just done, and you read the angles.

Questions

1. What angle do you get for the horizon sighting?
2. What angle do you get when you point directly above you? What is this point called?
3. What readings did you and your partner get for the classroom objects? Did the readings agree? Why or why not?
4. When you moved closer to the wall, what happened to the altitude of the point where ceiling and wall meet? Did the angle increase or decrease?

Conclusion

What can you say about the relationship between altitude and the observer? What about latitude-longitude and the observer?

tood′) of a star is its distance in degrees above the horizon. A star sighted on the horizon has an altitude of 0° with respect to the observer. A star sighted directly overhead has an altitude of 90° with respect to the observer. This point on the celestial sphere, which is directly over the head of the observer, is called the **zenith** (ZEE′-nith).

What is the altitude of a star that is directly above the head of an observer? What is this point called?

Notice that the altitude of a star is given with respect to the observer. The altitude of a star can vary greatly, depending on

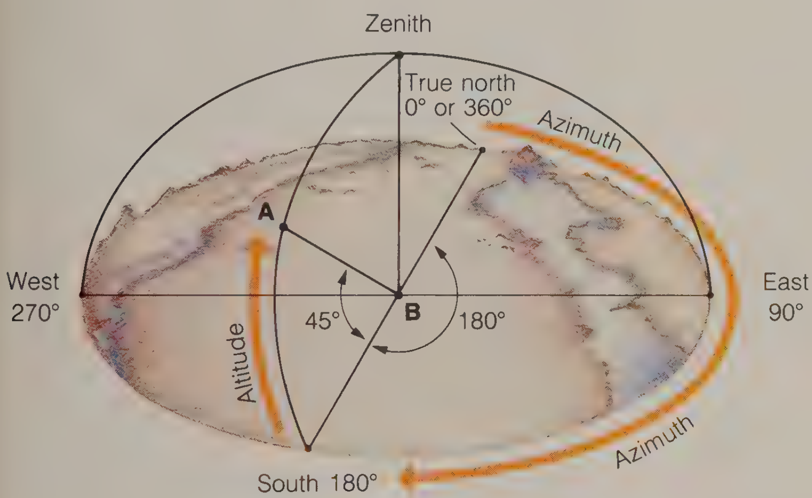


Figure 3-7. The star at Point A is located at an azimuth of 180° and an altitude of 45°. Where is the observer standing?

the location of the observer. Take, for instance, the altitude of **Polaris** (pō-LAR′-is), which is also called the North Star. At the North Pole, Polaris is directly over the head of an observer and therefore has an altitude of 90°. At the equator, however, the altitude of Polaris is 0°. An observer at the equator can therefore expect to find Polaris on the horizon.

Library research

Find out how ancient astromers knew that there was a difference between stars and planets.

If you recall what the latitude is at the equator and at the North Pole, you may have noticed the relationship between the altitude of Polaris and the latitude of the observer. At the equator, which is 0° latitude, the altitude of Polaris is 0°. At the North Pole, which is at 90° N latitude, the altitude of Polaris is 90°. If you lived at 43° N latitude, you could expect to find Polaris at an altitude of 43°. Latitude in the Northern Hemisphere can be determined by measuring the altitude of Polaris.

To locate a star on the celestial sphere, altitude alone is not enough. You also need a second measurement. Let's say that you are looking for a star with an altitude of 45°. That star

Activity Finding the Altitude of Polaris

Materials

astrolabe constructed for the Activity on page 122

Purpose

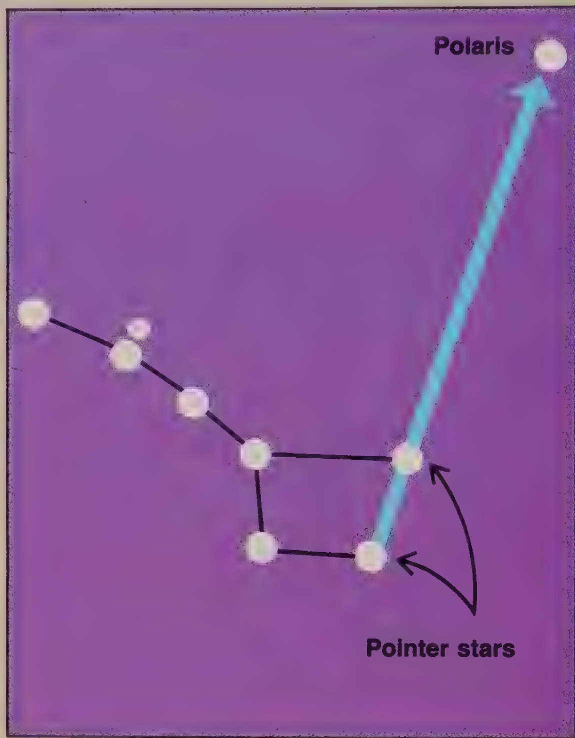
To find your latitude by measuring the altitude of Polaris.

What to Do

1. On the next clear night, locate the Big Dipper and then find Polaris. The illustration on this page shows how the "pointer stars" can help you find Polaris.
2. Use your astrolabe to measure the altitude of Polaris. It would be helpful if you had someone with you to read the angle on your astrolabe.
3. Record the altitude you measure for Polaris.
4. Check with your teacher or a map of your area and find the actual latitude of your community.

Question

How does the altitude you found for Polaris compare with the latitude of your community?



Conclusion

Explain the relationship between the altitude of Polaris and the latitude of a place where an observer stands.

could be anywhere on an imaginary circle that is 45° above the horizon. To be more precise, you also need to know where on that imaginary circle the star is located. This second measurement, which will provide that necessary information, is called the star's azimuth.

The **azimuth** (AZ′-uh-muth) of a star is its distance in degrees on the horizon as measured from true north. Azimuth begins at the true north line and runs completely around the horizon, 360° in a clockwise direction, until it reaches the true north line. The azimuth of a star like Polaris, which is on the true north line, can be either 0° or 360°. Figure 3-7 shows how to locate a star at an azimuth of 180° and an altitude of 45°.

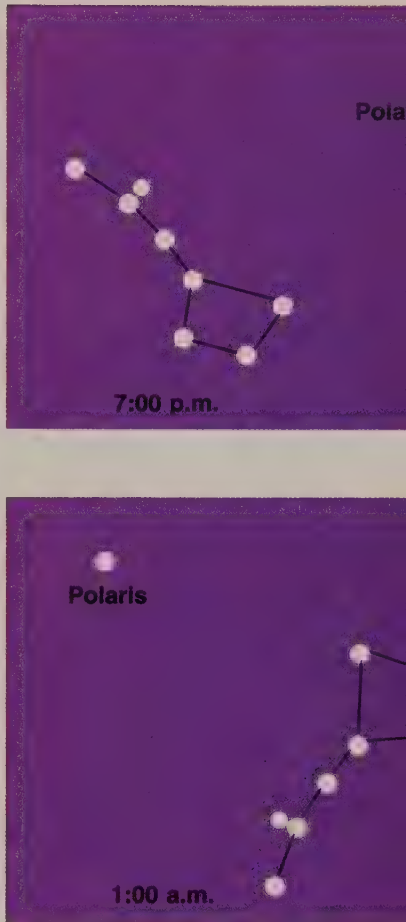


Figure 3-8. In six hours, the Big Dipper changed from the position on the top to the position on the bottom. How would the Big Dipper appear in another six hours?

Check yourself

1. In terms of describing a star's location, how do altitude and azimuth differ?
2. How can an observer in the Northern Hemisphere use the night sky to find his or her latitude?

Observations of motion

If you've ever looked at the moon at different times on the same night, you've seen that the moon changes its position in the sky. One way to show this is to take a time exposure with a camera. In a **time exposure,** the lens of the camera is kept open so that any movement of the objects is indicated by a blur.

Let's say that you could take a time exposure of the moon in the sky. What would you find on the film after the lens of the camera had been left open for several hours? You would find a blurry trail that is a record of the moon as it moved across the sky.

What about the stars? If you looked for the Big Dipper or for Orion at different times on the same night, would their locations in the sky have changed? Figure 3-8 shows how the position of the Big Dipper changes over a period of six hours. At 7:00 p.m., the handle of the Big Dipper pointed up and toward the observer's left. At 1:00 a.m., the handle of the Big Dipper pointed down toward the horizon. In another six

Activity Plotting the Paths of Four Stars

Materials

astrolabe constructed for use in the Activity on page 122
flashlight

Purpose

To follow the paths of four stars across the sky during one evening.

What to Do

1. Construct a chart similar to the one that begins on this page.
2. On a clear night, find a place in which you can observe stars. Try to find a place with little or no outside light. Determine the location of north, south, east, and west by first finding Polaris, or the North Star.
3. Use the pointer stars in the Big Dipper to find Polaris. As you can see from Figure 3-8, Polaris is located on a straight line with the outer two stars of the bowl of the dipper. Going in a straight line from those two stars, the first star that you come to will be Polaris. Don't be disappointed when you find Polaris. It is not very big or bright. It is just an ordinary-looking star.
4. Once you find Polaris, you know the direction of true north. Identify this direction with some type of marker (a tree, pole, etc.).
5. Choose markers that identify east, south, and west. By turning your astrolabe on its side, you can use it to locate these other directions. East is 90° to the right of north. South is directly opposite north, etc.
6. You should also mark the location on which you are standing. All your observations must be made from the same spot. (Use chalk if you are standing on a hard surface, or perhaps a rock for a grass surface.)

Data Table

Star	Location at ______ (time)	Location at ______ (1 hour later)	Location at ______ (2 hours later)
North Star (Polaris)	Azimuth: ___° Altitude: ___°	Azimuth: ___° Altitude: ___°	Azimuth: ___° Altitude: ___°

7. Select four stars that can easily be found again. One should be Polaris. The others should be very nearly east, south, and west.
8. On your chart, record the azimuth of each star. You can find the azimuth by using north as 0°, or the starting point. The azimuth of Polaris, therefore, is 0°. A star that is due east has an azimuth of 90°. The azimuth of a star due south is 180°, and the azimuth of a star due west is 270°.
9. You can find the azimuth of other positions by turning your astrolabe on its side. Use the string to measure the number of degrees the star is away from any one of the markers for north, east, south, or west.
10. Find the angle of elevation that each star is above your eye level. Sight the star with your astrolabe. Have a friend, using a flashlight, notice where the string passes the curved edge of the protractor. Always use the reading that is less than 90°. No altitude can be greater than 90°. On your chart, record the altitude for each of the four stars.
11. Repeat these readings two more times, at exactly one-hour intervals. Use the same stars each time. Record all data.

Question

How many degrees of azimuth and altitude did the stars move in one hour? in two hours?

Conclusion

Can you predict how many degrees the stars will appear to move in 24 hours? What does this motion tell you?

hours, at 7:00 a.m., the Big Dipper would have completed another quarter turn. Its handle would be curving off to the observer's right.

Figure 3-8 also shows the relationship between the Big Dipper and Polaris. In Figure 3-8 you will note that the two stars that form the outside edge of the Big Dipper's bowl point to Polaris. Even as the Big Dipper changes position, those two pointer stars will still lead your eye to Polaris.

Figure 3-9 shows a time exposure of the northern night sky. In a time exposure, the shutter of a camera is held open so that any motion of the objects in front of the camera is recorded on the film. The curved lines in Figure 3-9 are **star traces** or trails. They are a record of the motion of the stars as "seen" through the lens of the camera during the time that the shutter was held open. Polaris is located very close to the center of the star traces. Polaris therefore remains in just about the same location on the celestial sphere. All the other stars seem to be moving around Polaris.

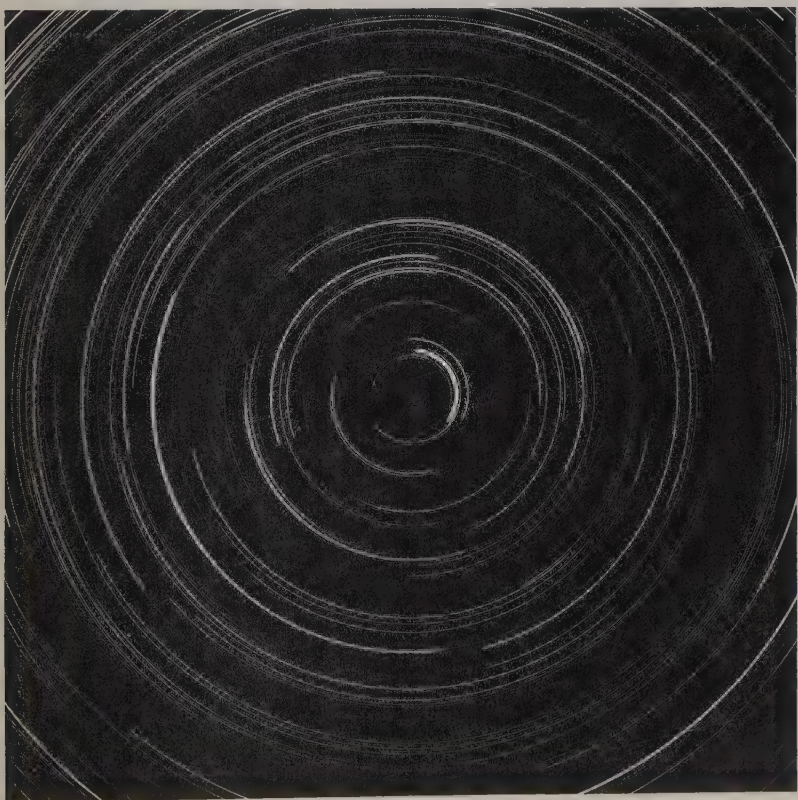
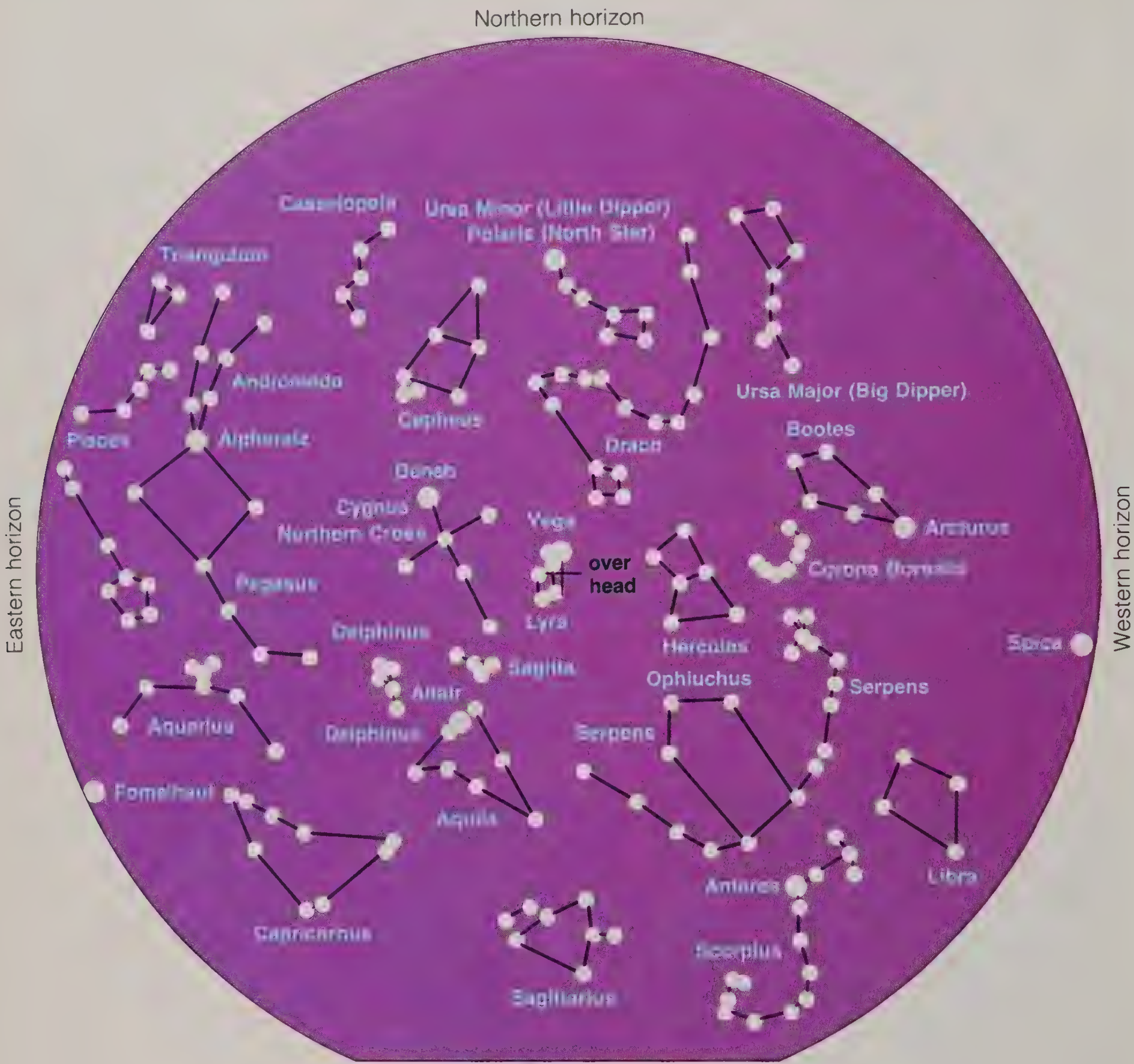


Figure 3-9. The photograph is a time exposure of the night sky. What are the curved lines?



The Night Sky in August

Library research

Prepare a report on a scientist who made a contribution to astronomy. Names to consider: Tycho Brahe, Nicholas Copernicus, Johannes Kepler, Galileo Galilei.

Star traces are evidence of a kind of motion that can be observed over a period of minutes and hours. A second kind of motion can be observed only over a period of weeks and months. During this time, there is a change in the stars and constellations that appear in the night sky. Some stars and constellations can be seen only at certain times of the year. Orion, for example, cannot be seen in the Northern Hemisphere on a summer night. Orion will not appear in the northern night sky until well into the fall. Figure 3-10 shows how a northern night

The Night Sky in April

sky in August differs from a northern night sky in April. Section 2 and Section 3 of this chapter will offer reasons for the two different kinds of motion in the night sky.

Figure 3-10. Some stars and constellations can be seen at only certain times during the year. Compare the star map on this page with the one on the facing page. What do you notice about Orion?

Check yourself

1. Describe how star traces are evidence of motion.
2. What other feature of the night sky is also an evidence of motion?

Section 1 Review Chapter 3

Check Your Vocabulary

altitude	Polaris
azimuth	star traces
celestial sphere	time exposure
constellation	zenith
horizon	

Match each term above with the numbered phrase that best describes it.

1. The point where, to an observer, the earth and sky appear to meet
2. The imaginary sphere on which all objects in the sky seem to be located
3. A group of stars in which some people have imagined the outline of a person or animal
4. The distance in degrees of a star above the horizon
5. The point on the celestial sphere that is directly above the head of an observer
6. The north star
7. The distance of a star in degrees on the horizon as measured from true north
8. A photograph that records the motion of a moving object because the lens of the camera was kept open
9. Curved lines caused by the apparent movement of stars while a time-exposure photograph was being taken; also called star trails

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The pointer stars in the bowl of the Big Dipper point toward _?_.
   a) Sirius c) Orion's belt
   b) Polaris d) Canis Major
2. Rigel and Betelgeuse are _?_.
   a) stars c) constellations
   b) star groups d) imaginary
3. Azimuth and altitude are used to describe the _?_ of a star.
   a) brightness c) color
   b) latitude d) location
4. The stars are really located _?_.
   a) on a huge dome
   b) on the horizon
   c) at many different distances from the earth
   d) directly above an observer's head
5. At the _?_, the altitude of Polaris is 0°.
   a) North Pole c) equator
   b) South Pole d) North or South Pole

Check Your Understanding

1. Describe the celestial sphere. Include an explanation of where the center of the celestial sphere is located.
2. Is the horizon the same for all observers? Explain.
3. Does the zenith change as the observer changes position on the earth? Explain.
4. List the azimuth of north, east, south, and west.
5. Describe two evidences of motion that are provided by the night sky.

The Earth Rotates   Section 2

Section 2 of Chapter 3 is divided into five parts:

Evidence of the earth's rotation

Some effects of the earth's rotation

The Coriolis effect

The time of day

East into yesterday, west into tomorrow

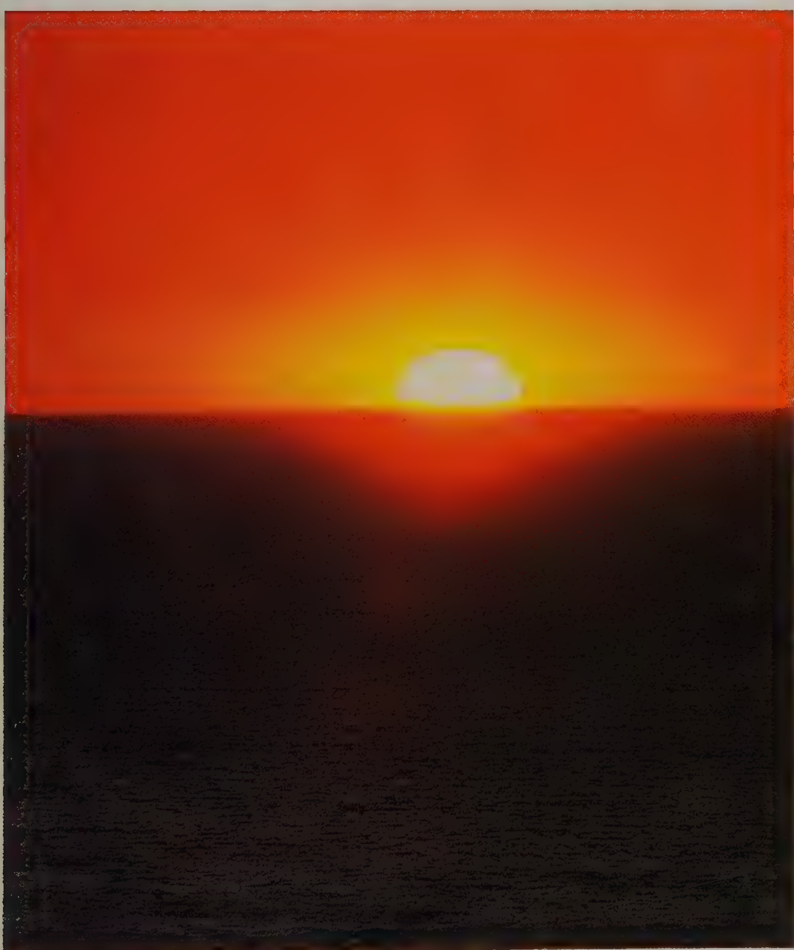


Figure 3-11. At sunset, you may have looked up to see the sun near the horizon. The next moment, the sun was gone. What appears to have moved?

You have seen the sun rise, move across the sky, and then sink below the horizon. What is moving—the earth or the sun?

You have learned that the stars move in the sky. What is moving—the stars or the earth?

You know that part of each day is in sunlight and part is in darkness. What is moving—the earth or the sky?

If you were to ask a young child what is moving, chances are the child would say the sun, the stars, and the sky move. They are what seem to be moving. And to prove otherwise is not an easy task.

Evidence of the earth's rotation

Does the earth give any direct proof that it is moving? It is so large and we are so small that it does not appear to be the huge merry-go-round that it really is. It is very easy to think that the earth is standing still and the sky and all the objects in the sky are moving.

Today we know that the daily rising and setting of the sun are caused by an earth motion. We know that the motion of the stars that appear to move around Polaris in a time exposure is caused by the same kind of earth motion. The earth is actually turning or spinning around. Once every twenty-four hours the earth turns completely around on its axis. This daily turning of the earth on its axis is called **rotation.**

The earth is said to rotate on its axis. The earth's axis is not like the stick that passes through the North Pole and the South Pole of a globe. The **axis** is an imaginary line around which the earth appears to be turning. You can observe an axis by spinning a ball and looking down on the ball as it is spinning.

Is the earth's axis a real line or an imaginary line?

The problem of whether or not the earth has motion has been argued about for two thousand years. The followers of Pythagoras (puh-THAG′-er-is), a Greek who lived in the sixth century B.C., believed that the earth rotates on an axis. But they could offer no proof for their belief.

In 1851, Jean Foucault (ZHON foo-KŌ′), a French physicist, developed a device that demonstrated the earth's rotation to

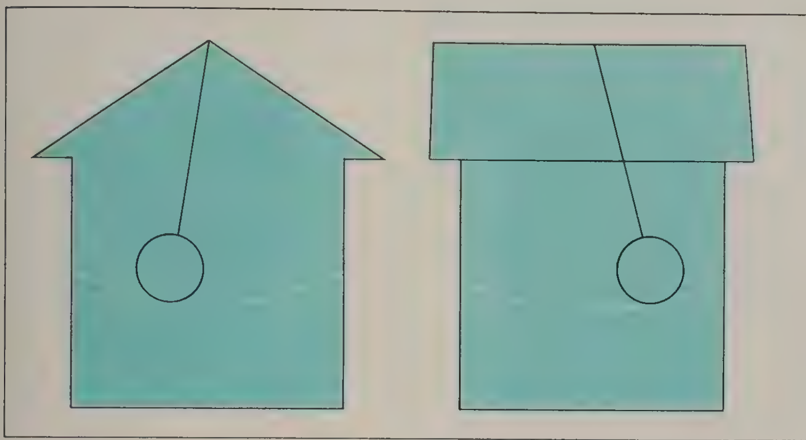


Figure 3-12. A Foucault pendulum may appear to change the direction of its swing. What is really changing direction?

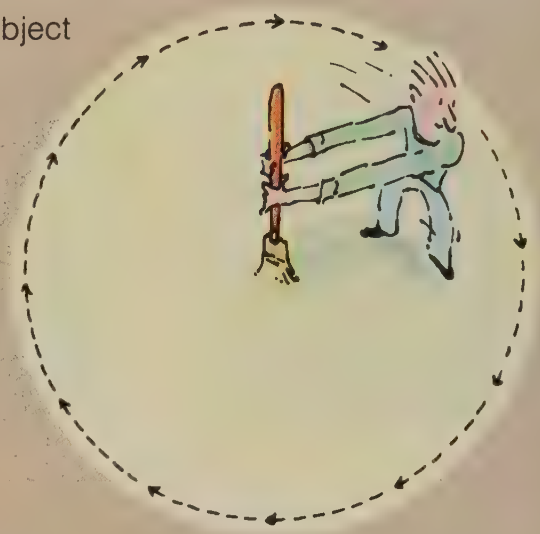
many people. Foucault set a pendulum swinging in a north-south line. With a pendulum, once it is set in motion it will tend to continue swinging in the same direction. It cannot change the direction of its swing. But Foucault noticed that during each swing, the pendulum appeared to shift away from the north-south line in a clockwise direction.

Foucault announced that it wasn't the pendulum that was changing direction. Rather it was the floor of the building that was turning. But the building was firmly attached to the earth. The pendulum, therefore, demonstrated that it was the earth that was turning and that the earth was carrying the building with it.

For an observer on the earth, it may be difficult to imagine a whole building turning under a pendulum. This is especially true when you are standing in the building and can feel no motion. But if you lived on a space platform you could observe the earth from space. You would then be able to see the land masses and the oceans appear and disappear as the earth rotates on its axis.

Satellites in polar orbit offer further evidence that the earth is rotating. A satellite in polar orbit passes over the North Pole and the South Pole. As shown in Figure 3-13, each time that such a satellite recrosses a latitude between the poles, it passes further to the west. This indicates that the earth is rotating from west to east.

Activity Observing the Axis of a Rotating Object



Materials

ball
masking tape
broomstick or long dowel

Purpose

To observe the axis of a rotating object. To understand the differences between real and apparent motion.

What to Do

1. Take the ball and spin it. Stand directly over it. Look for a point around which the ball is spinning.
2. Try spinning the ball at different speeds. Notice the difference between a fast spin and a slow spin.
3. With masking tape, put an X on the ceiling to represent Polaris. (You could also put masking tape on the ceiling in various patterns to represent stars.)
4. Take the stick and hold it straight up and down under the X (for Polaris) that is on the ceiling. Slowly begin rotating your body around the stick so that your body turns but the stick does not change its position, as shown in the diagram. The stick should remain pointing to Polaris at all times.
   SAFETY NOTE: *Do not turn too quickly, or you will get dizzy.*
5. As your body is slowly rotating around the stick, focus your eyes on objects in the room. Note whether they appear to move.
6. Focus your eyes on the other end of the stick. Turn slowly around. The stick moves as you move.

Questions

1. When you spin the ball, can you see a point around which the ball is spinning?
2. What is the difference between a fast spin of the ball and a slow spin?
3. When your body is rotating around the stick, do the objects in the room appear to move?
4. As you move around the stick, it moves as you move. But did it travel any distance? Did the end of the stick appear to remain in the same place, like Polaris in the night sky?

Conclusion

What have you learned about apparent motion and real motion?

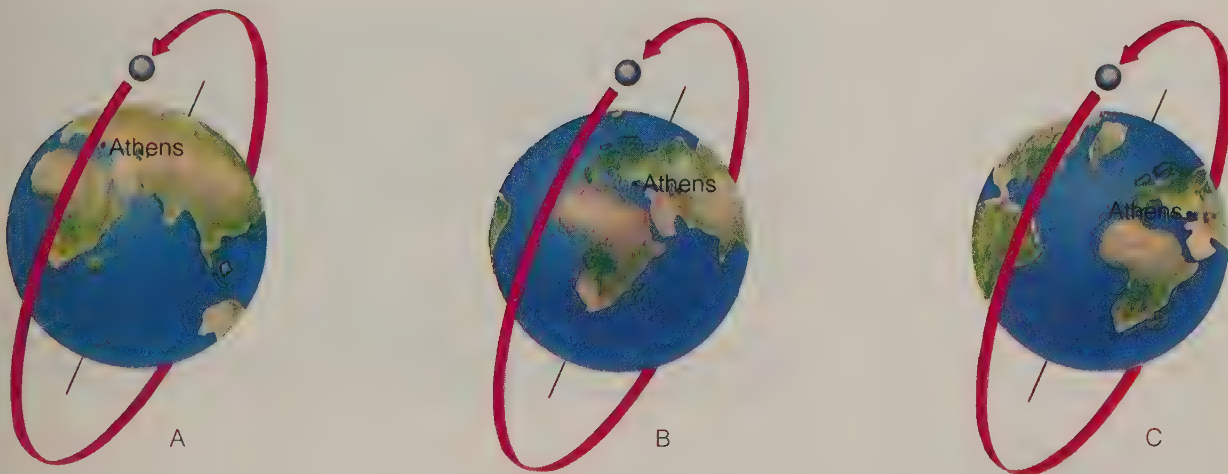


Figure 3-13. A satellite in polar orbit keeps passing over the North Pole and the South Pole. In locations away from the poles, a satellite moves to the west with each return trip.

Check yourself

1. What is meant by the term *earth's rotation?*
2. How does the Foucault pendulum demonstrate that the earth is moving?

Some effects of the earth's rotation

What effects does rotation have on the earth? As already stated, the apparent rising and setting of the sun are caused by the earth's rotation. The apparent daily motion of the stars is another effect of the earth's rotation.

If you were to stand on the equator and observe a star on the eastern horizon at exactly 7:00 p.m. and again at 8:00 p.m., you would find that the star had risen above the horizon exactly 15°. One hour later, it would have risen another 15°. This is because in the course of a day, the earth turns 24 × 15° or 360°, or in one complete circle.

Day and night on earth are also caused by the earth's rotation. Because of the solid composition of the earth's lithosphere, the sun's rays cannot pass through the earth. This means that one side of the earth receives sunlight and the other is in darkness. At any one instant, exactly half the earth has daylight and half has darkness.

Figure 3-14. What would happen if this child let go while the merry-go-round was spinning fast?

Library research

The Twilight Zone was a popular TV series. What is the twilight zone on earth? What causes it?

Another effect of the earth's rotation has to do with the shape of the earth. As mentioned in Chapter 1, the earth is not a perfect sphere. Rather, there is a slight flattening at the poles and a slight bulge at the equator. (The earth's circumference, if measured around the equator, is 40 076 km. If measured through the poles, the circumference is 40 008 km.)

If you've ever been on one of those small merry-go-rounds at a playground, you know what happens to a spinning object. As the merry-go-round is pushed around faster, it is harder to hold on. If you let go, you'd go flying right off and onto the ground.

This same effect causes the earth to bulge slightly at the equator. This may seem hard to believe because we think of the earth as a solid. But the fact is that solids will bend when there is great force over long periods of time. Also, there is evidence that the interior of the earth is not solid and that the "solid" crust we live on was at one time a liquid. There is also evidence that the "solid" crust we live on is now made up of huge floating plates.

The bulge at the equator is very slight. The flattening at the poles is very slight. But both are probably caused by the rotation of the earth.

Check yourself

1. Name four effects of the earth's rotation.
2. Is the earth a perfect sphere? Explain.

The Coriolis effect

The entire earth turns as a whole. It makes one rotation every twenty-four hours. But, as shown in Table 3-1 below, the earth's surface moves at different rotational speeds, depending upon location. This difference in speed might be easier to imagine if you think of the earth as a huge wheel going around. The outside of the wheel goes faster than the inside of the wheel. The merry-go-round at the playground shows this to be true. If you stand next to the center pole, you can hold on very easily—even when the merry-go-round is spinning fast. The same cannot be said if you were to stand near the outer edge.

Do all locations on the earth's surface travel at the same rotational speed?

Differences in the earth's rotational speeds cause objects moving north or south above the earth's surface to seem to move in a curved line rather than in a straight line. Imagine a baseball pitcher who tries to throw a straight pitch but the ball always curves to the left or to the right. Because all the earth's surface does not rotate at the same speed, that is what happens to objects that move north or south above its surface. They appear to curve toward the east or the west because of changing speeds in the part of the earth's surface that is moving under the object.

How do differences in the earth's rotational speeds affect objects moving freely above the earth's surface?

When a moving object is forced from a straight line of travel, we say that it is **deflected.** In the Northern Hemisphere, objects moving north above the surface of the rotating earth seem

Different Rotational Speeds of the Earth			
Location on the Earth	Distance Around the Earth at This Latitude	Time of One Complete Rotation	Rate of Rotational Speed at Each Latitude (Distance ÷ Time)
0° latitude (equator)	40 000 km	24 hrs	1670 km/hr
30° latitude	37 704 km	24 hrs	1446 km/hr
60° latitude	20 040 km	24 hrs	835 km/hr
90° latitude (North/South Pole)	0 km	24 hrs	0 km/hr

Table 3-1. A location on the equator has a greater rotational speed than a location at any other latitude because it travels the greatest distance in a day. About how many kilometers does a location on the equator travel in a day?

Activity Simulating the Coriolis Effect

Materials

rotating platform, 30 cm in diameter

aluminum pie tin, 23 cm in diameter

water

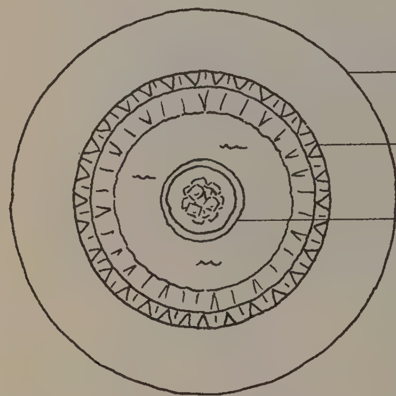
ice

food coloring (blue or red)

paper cup

pin

Aerial view



Purpose

To simulate the Coriolis effect.

What to Do

1. Place the pie tin on the rotating platform and fill with water to within 1.5 cm from the top.
2. Take a small paper cup and put four pinholes near the base of the cup. Space the holes equally around the cup.
3. Place some crushed ice in the cup (about ¾ full). Place the cup in the center of the pie tin with the water in it.
4. Begin to turn the rotating platform very smoothly in a counterclockwise direction. This will simulate the earth's rotation. To obtain the desired results, the platform must be kept rotating slowly and constantly.
5. Have another student add several drops of food coloring to the cup with the ice. Next, your partner should add a small amount of water to the ice and food coloring.

Questions

1. As the food coloring comes out of the pinholes, does it move in a straight line toward the edge of the pie tin?
2. How would you describe the direction the food coloring takes as it moves away from the cup? (A drawing will help.)
3. Why does this apparent deflection take place?

Conclusion

Can you predict what would happen if you rotated the platform in a clockwise direction? (If time permits, repeat the activity, but rotate the platform in a clockwise direction. Was your prediction correct?)

to be deflected, or turned aside, toward their right. In the Southern Hemisphere, objects are deflected toward their left. This so-called deflection of freely moving objects was first explained in 1835 by Gaspard de Coriolis, a French mathematician. As a result, this so-called deflection of freely moving objects is known as the **Coriolis effect** (kor′-ee-Ō′-lis uh-FEKT′).

Suppose you lived in Houston, Texas, which is located at 30° North latitude. You have a friend who lives in Minneapolis, Minnesota, which is at 45° North latitude. Because you are in Houston, you would be traveling at 1446 km/hr toward the east. Your friend in Minneapolis would be traveling at only 1183 km/hr.

Suppose also that you decide to fire a rocket with a message in it due north to your friend in Minneapolis. Since you have a rotational speed of 1446 km/hr, the rocket also has this sideways speed at the time that it is fired. As the rocket heads north, it seems to be deflected to the east and comes down in Milwaukee. Arrow B in Figure 3-15 shows this deflection, which is caused by the difference in rotational speed of the earth at different latitudes. Minneapolis was not rotating as rapidly toward the east as Houston, where you launched the rocket.

What if your friend in Minneapolis fired a rocket due south to you in Houston? It would then seem to be deflected to the west. This time, the rocket would come down in San Antonio, Texas. Arrow C in Figure 3-15 indicates the path of the rocket when it is fired from a slower moving object toward a faster moving object.

The Coriolis effect also causes the earth's wind patterns and the earth's ocean currents to be deflected. If the earth were not rotating, the air near the earth's surface would flow mostly north and south in straight lines between the poles and the equator. The earth's ocean currents would also flow mostly north and south in straight lines. But because of the Coriolis effect, these north-south patterns seem to move in a curved path. This deflection greatly affects the weather patterns and climates of the earth.

You can see the Coriolis effect by placing a dot in the center of a piece of paper. Place your pencil on the dot and try to draw a straight line to the edge as you turn the paper quickly

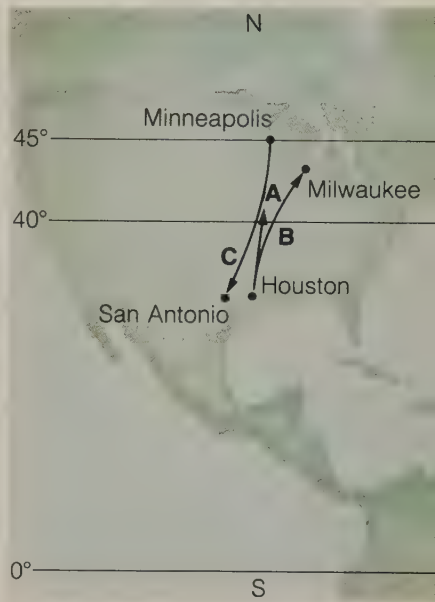


Figure 3-15. Arrow A would be the path of a rocket on a non-rotating earth. Arrow B would be the path above the rotating earth and illustrates the Coriolis effect.

Library research

The difference between mean solar time and apparent solar time is called the equation of time. It varies ±16 minutes during the year. Find out the four times each year when the correction is zero. Find out where the corrections for each day can be found.

counterclockwise with the other hand. Any line you draw will curve to its right as it moves from the center of an object rotating in a counterclockwise direction.

Check yourself

1. At Houston, the earth's surface is traveling at 1446 km/hr toward the east. At Minneapolis, the earth's surface is traveling at only 835 km/hr. Explain.
2. As a freely-moving object travels above the earth's surface, the earth's surface is also traveling because of its own motion. How does this earth motion cause an apparent deflection in the path of a freely-moving object above the earth's surface?

The time of day

At any one moment, how much of the earth's surface is experiencing daytime?

What time of day is it? Actually, it is possible to choose any one of several kinds of time for any place on the earth. One kind of time is measured from noon. At any one moment, half of the earth's surface is facing the sun, and it is daytime. And in the half of the earth that is in daylight, one much smaller part of that half is in the noon position.

As shown in Figure 3-16, the **noon position** is when the sun crosses the north-south line for an observer. The earth is rotating from west to east. The earth's rotation keeps bringing more westerly cities into the noon position. Points to the east of the noon position begin to see the sun sink in the sky. Determining time by using the sun is called **apparent solar time.** *Solar* is from the Latin word for the sun.

A second method of determining the time is called **mean solar time.** Mean solar time is based on the average length of a day, from noon to noon. The average length of a day, based upon one complete rotation under the sun, is twenty-four hours.

Mean solar time is the time given by common clocks. It is necessary to use a mean, or average, time because the earth has little variations in its rotation and other motions. These varia-

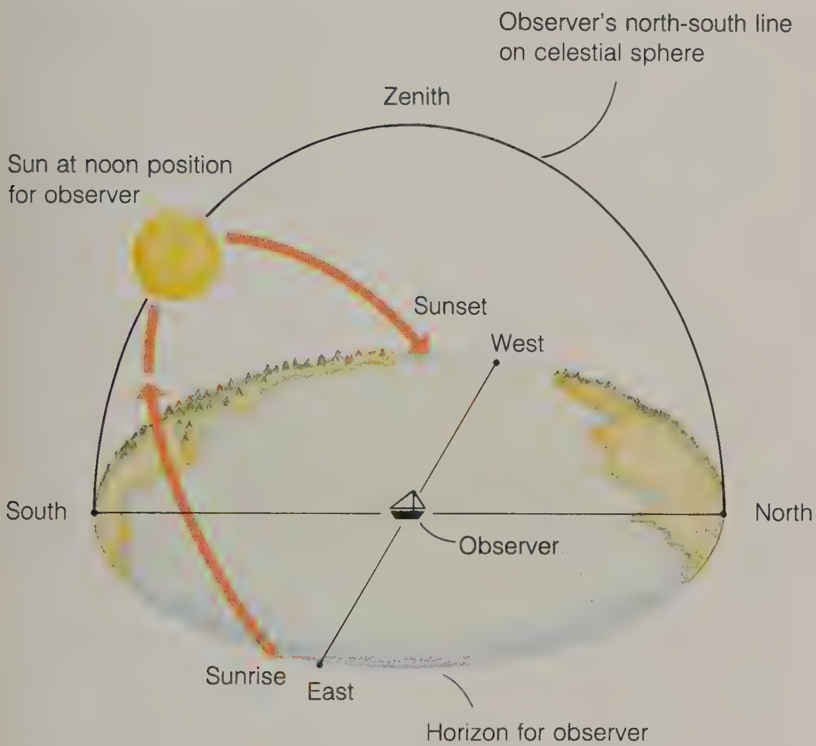


Figure 3-16. At any moment, a small portion of the earth is in the noon position. When is it noon for an observer in any location on the earth's surface?

tions cause the length of a day to vary. But it would be annoying if we had to keep adjusting our clocks every day. And this would create problems with train, bus, and airline schedules. An average day-length of twenty-four hours is more practical.

If we were not on mean (average) solar time, how often would we have to adjust our clocks and watches?

Apparent solar time and mean solar time are only two methods used to determine time at a particular location on the earth. Because of the earth's rotation, noon, midnight, or any other time moves around the earth from east to west.

It is possible to tell what time it is at any place on earth because of what are called time zones. A **time zone** is a north-south section of the earth in which all clocks indicate the same time. When it is noon in Toronto, Canada, it is also noon in Havana, Cuba. As shown in Figure 3-17, Toronto and Havana are in the same time zone. But when it is noon in Toronto, it is only 9:00 a.m. in Vancouver. That is because Vancouver is west of Toronto and is in a different time zone.

According to mean solar time, the average length of a day is twenty-four hours. The earth rotates 360° in 24 hours, or 15°

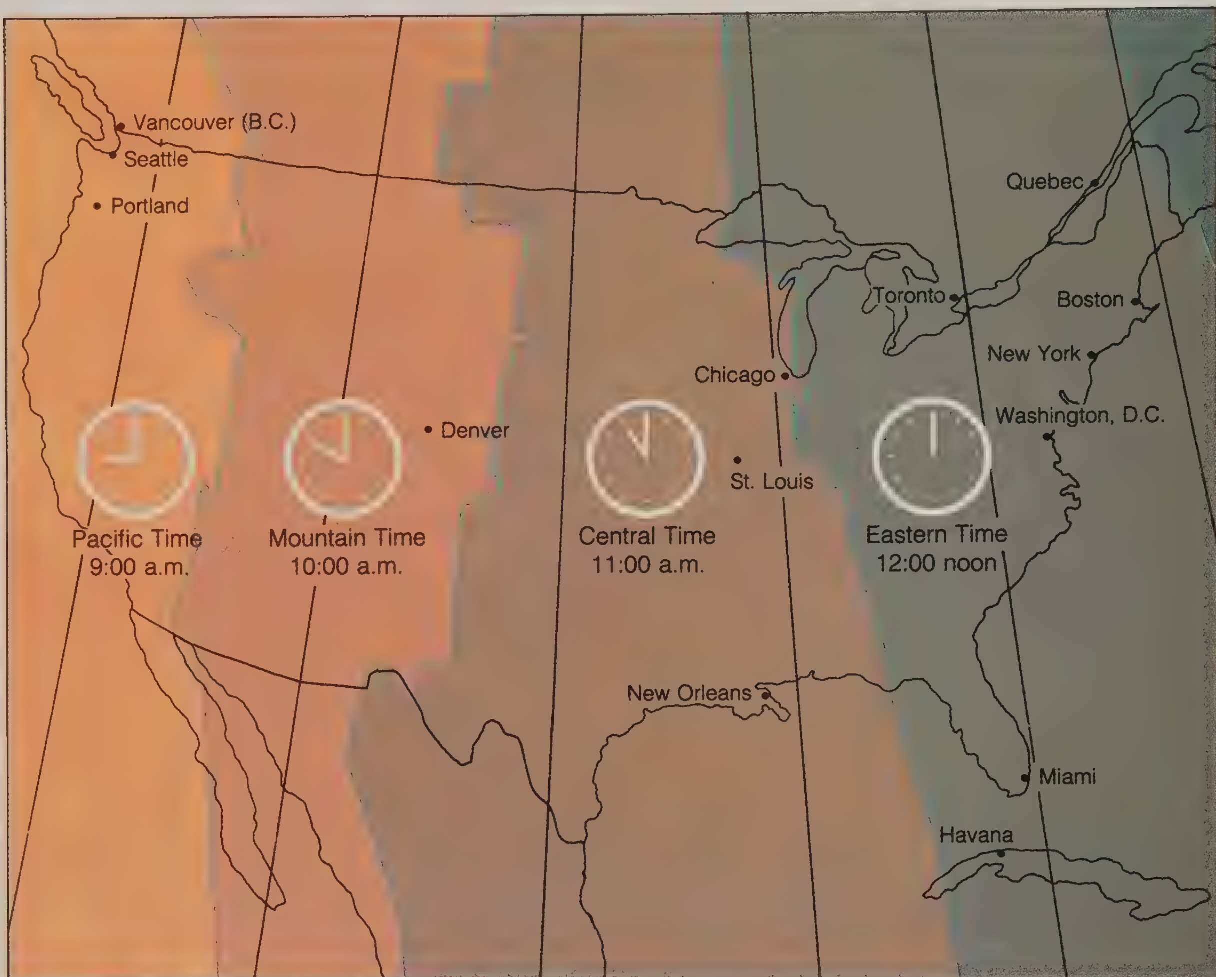


Figure 3-17. Toronto and Havana are in the same time zone. What is a time zone?

in 1 hour. As a result of this, a place with a longitude 15° west of you will have a time one hour earlier than your time. A place 15° east of you will have a time one hour later than your time.

As shown in Figure 3-18, each meridian of longitude that is a whole multiple of 15° is the center of a time zone. Meridians 7½° east and west of the central meridian are the boundaries. New York City is east of the 75th meridian. All points between 7½° east and 7½° west of the 75th meridian observe the same time.

Some other times you have probably heard of are Greenwich mean time and daylight-saving time. **Greenwich mean time** is the mean solar time on the prime meridian (0° longitude).

Figure 3-18. The center of each time zone is a meridian that is a whole multiple of 15°. How far to the east and west of that central meridian does the time zone extend?

Greenwich mean time is used as a standard for determining time throughout most of the world.

You can use local time and Greenwich mean time to find longitude. Let's suppose it is 3:00 p.m. at Greenwich and 10:00 a.m. where you live. You are five hours earlier than Greenwich mean time so you are five time zones away. $5 \times 15°$ is 75° away from Greenwich. Since you are earlier than Greenwich, you are west of the prime meridian. You must be somewhere around 75° West longitude. If your time were later than Greenwich, you would be east of the prime meridian.

Mean solar time is a standard time that is based on the position of the sun. Standard time can be replaced by what is called

Library research

Daylight-saving time was used during World War II. For what reason? Why is it used today? Can daylight-saving time be used to save energy? See what you can find out about daylight-saving time and make a list of the pros and cons about its use.

daylight-saving time. During **daylight-saving time,** clocks are moved ahead one hour from the standard time. This changing of the clocks does not affect the number of hours of daylight in a day. It merely shifts the whole time frame ahead one hour. According to this adjusted time frame, sunrise and sunset occur one hour later. A sunset at 5:30 p.m. standard time will occur at 6:30 p.m. daylight-saving time. This is done to provide an hour more of daylight *at the end* of a working day. In the spring, the clocks are set ahead one hour. In the fall, we move the clocks back to standard time. An easy way to remember this is "Spring forward. Fall back."

Check yourself

1. What is the difference between apparent solar time and mean solar time?
2. Why is it necessary to have time zones around the earth?
3. What is Greenwich mean time?

East into yesterday, west into tomorrow

Look at the times of the various meridians in Figure 3-19. You can see that it is Friday to the east of the 180th meridian. To the west of the 180th meridian, it is Saturday. From one side of this imaginary line to the other, there is a difference of twenty-four hours—one whole day. Since a day must begin somewhere on the earth, the nations of the world have agreed that it begin at the 180th meridian. This meridian has a special name. It is called the **International Date Line.**

Look again at Figure 3-19. Observe that the International Date Line mostly follows the 180th meridian, which is farthest from the prime meridian. In some places, however, the Date Line has been bent to avoid problems or confusion. Russia, for instance, wanted all of Asia to be on the same side of the International Date Line. And certain islands did not want to be split by the line, so they selected to be either to the east or to the west of the Date Line.

Why isn't the International Date Line a straight north-south line along the 180th meridian?

When a ship sails east across the Date Line, the ship sails into yesterday. The ship's calendar will repeat one full day. When a ship sails west across the Date Line, the ship sails into tomorrow. The ship's calendar will move ahead one full day.

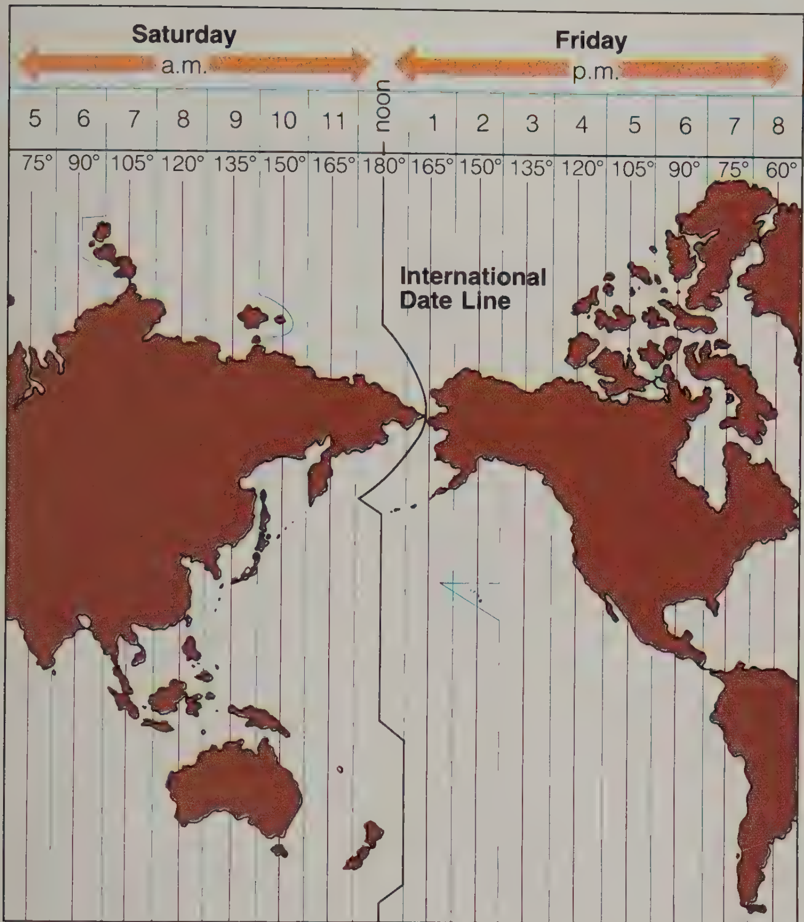


Figure 3-19. When it is Friday to the east of the International Date Line, it is Saturday to the west of the International Date Line. How does this affect the calendar of a ship sailing east across the Date Line?

It is important to remember that when you cross the Date Line only the date changes. The time does not change. If you are traveling west and cross the Date Line at 2:05 p.m. on a Monday, you will immediately find yourself at 2:05 p.m. on a Tuesday. If you were traveling east, you would have gone from 2:05 p.m. on a Monday to 2:05 p.m. on Sunday, the day before. When thinking of the International Date Line, this saying may help: East into yesterday, west into tomorrow.

Check yourself

1. What is the International Date Line?
2. Explain the significance of "East into yesterday, west into tomorrow."

Section 2 Review Chapter 3

Check Your Vocabulary

apparent solar time	Greenwich mean time
axis	International Date Line
Coriolis effect	mean solar time
daylight-saving time	noon position
deflected	rotation
	time zone

Match each term above with the numbered phrase that best describes it.

1. The daily turning of the earth on its axis
2. An imaginary line around which the earth appears to be turning
3. Forced from a straight line of travel
4. The apparent deflection of an object that is traveling above the earth's surface; caused by differences in rotational speeds on the earth's surface
5. An adjusted time during which clocks are one hour ahead of standard time to provide an hour more of daylight at the end of a working day
6. An imaginary line agreed upon as the starting point for a day on the earth; the 180th meridian
7. The position of the sun when it crosses the north-south line for an observer
8. Time as determined by using the actual position of the sun
9. Time that is based on the average length of a day, from noon to noon
10. A north-south section of the earth in which all clocks indicate the same time; includes all points 7½° east and west of a central meridian which is a whole multiple of 15°
11. The mean solar time on the prime meridian, which passes through Greenwich, England

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The earth rotates _?_.
   a) once every twelve hours
   b) from west to east
   c) from east to west
   d) once a year
2. One complete rotation is _?_.
   a) 0° c) 180°
   b) 90° d) 360°
3. At any one instant, _?_ of the earth has daylight.
   a) one half c) one quarter
   b) one third d) more than half
4. In the _?_, clocks are set ahead one hour to begin daylight-saving time.
   a) winter c) summer
   b) spring d) fall

Check Your Understanding

1. Describe how the Foucault pendulum demonstrates that the earth is moving.
2. Draw a diagram of the earth from above the North Pole. Draw an arrow that shows the direction in which the earth is rotating.
3. Explain what causes objects moving above the earth's surface to appear to move in a curved path rather than in a straight line.
4. Two observers are hundreds of kilometers apart, but the sun is in the noon position for each observer at exactly the same time. What can you infer about the location of each observer?
5. Describe the International Date Line. Why is there one? Where is it? How does it affect travelers?

The Earth Revolves Section 3

Section 3 of Chapter 3 is divided into five parts:

Yearly changes in the night sky

The Doppler effect on starlight

The inclination of the earth's axis

The seasons

The time of the year

Figure 3-20. This space satellite travels in an orbit around the earth. How is the earth similar to a space satellite?

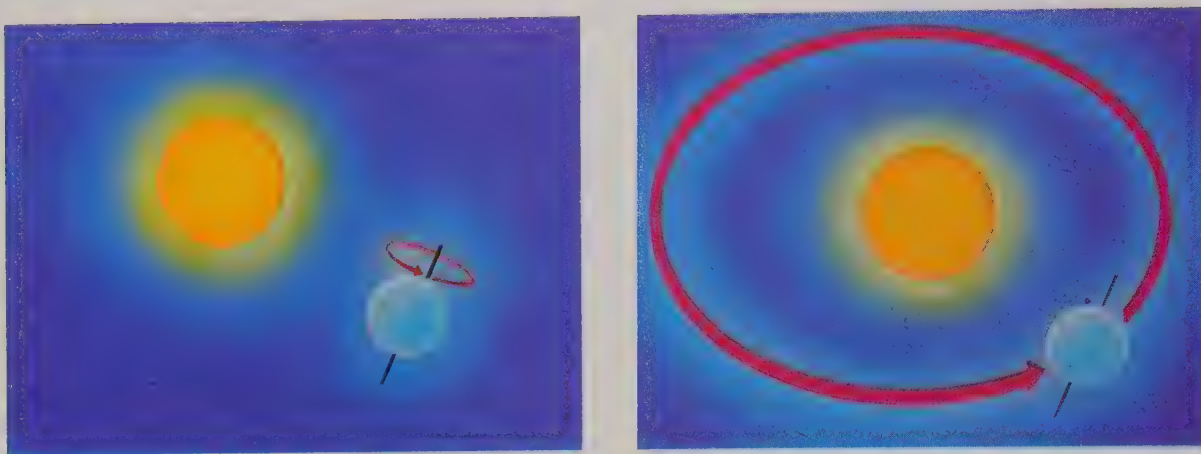


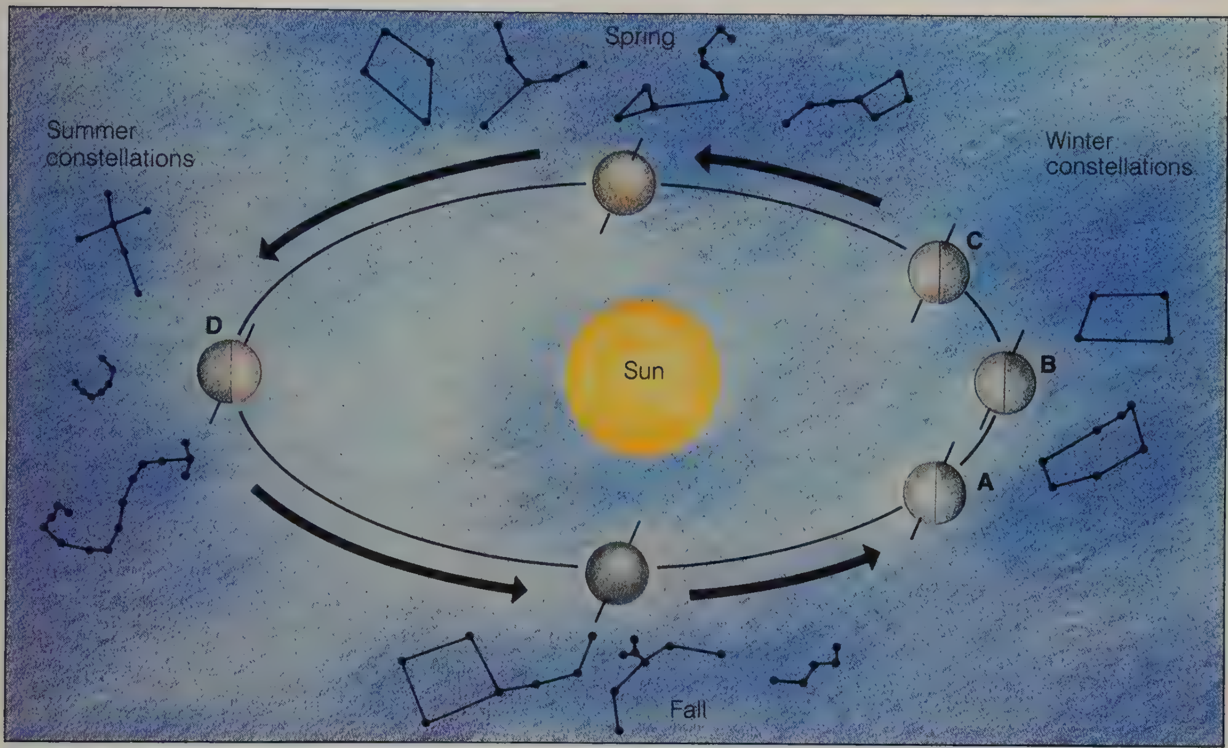
Figure 3-21. The diagram on the left shows the earth's rotation. What does the diagram on the right show?

Certain stars appear to move around Polaris once each day. This motion can be explained by the earth's rotation. The sun appears to rise and set each day. This motion can be explained by the earth's rotation. But there are other apparent motions of the sun and stars that cannot be explained by the earth's rotation. They can, however, be explained by a second earth motion. They can be explained if the earth is revolving around the sun.

Yearly changes in the night sky

When we say that the earth rotates, we mean that it spins on an imaginary axis. The diagram on the left in Figure 3-21 shows the earth's rotation on its axis. The diagram on the right in Figure 3-21 also shows the earth rotating on its axis. But it also shows the earth revolving around the sun. **Revolution** is the motion of the earth around the sun. The path that the earth follows as it travels around the sun is called the earth's **orbit.** You have seen pictures of space satellites that are orbiting the earth. At the same time that a satellite orbits the earth, the earth itself is in orbit around the sun.

If the earth is considered as revolving around the sun, then certain changes are much easier to explain. One example of such changes is the yearly changes that take place in the night sky. Certain stars can be seen in the night sky on any clear night



of the year. But Orion and some of the other constellations and stars can be seen only at certain times of the year. Figure 3-22 shows how an orbiting earth helps to explain yearly changes in the night sky.

Figure 3-22. Why can't the winter constellations be seen when the earth is at Position D?

Imagine yourself an observer on the earth at Position A in Figure 3-22. It is 8:00 p.m. on a winter evening. You are on the dark portion of the earth, where it is nighttime. In the night sky in winter, you can see such constellations as Orion, Gemini, and Canis Major.

Now imagine yourself weeks later at Positions B and C. The earth has moved along on its orbit. Again you observe at 8:00 p.m. so that you can compare what you observed the first night of observation. When you look up into the sky, you can still see the winter constellations. But their positions in the sky have changed. And it's a different kind of change than the one caused by the daily rotation of the earth.

The winter constellations appear to have moved because they are in a different position in relation to you, the observer.

Library research

Using reference books, prepare a report about the Stonehenge mystery. There are many theories, especially about how the large rocks were moved from a faraway place.

Where can circumpolar stars be found on any clear night of the year?

The earth is traveling in orbit about 1° per day. This change in position is so small that you wouldn't even notice it after several days had passed. After several weeks, however, the change in position would be noticeable.

As the earth continues its journey around the sun at a rate of about 1° per day, some new stars and constellations come into view. Others can no longer be seen. Look again at Figure 3-22. Imagine that you are now on the earth at Position D. The night sky now faces the summer constellations. The winter constellations are now part of the daytime sky. And they cannot be seen during the day because the light from the sun makes it impossible to see them.

Some stars, as you recall, are visible the year round, regardless of where the earth is in relation to the sun. These stars, which are located near and above the earth's North Pole and South Pole, are called **circumpolar stars.** The word *circumpolar* comes from two Latin words that mean around *(circum)* a pole. Circumpolar stars are always found around the North Pole or the South Pole on the celestial sphere on any clear night of the year.

Check yourself

1. Draw a simple diagram of the earth and sun. Use an arrow to show the earth's rotation. Use another arrow to show its revolution.
2. Do changes between summer constellations and winter constellations offer evidence of the earth's rotation or revolution? Explain.

The Doppler effect on starlight

To say that the earth revolves around the sun is one thing; to offer evidence for the earth's revolution is quite another matter. The earth is so large that people do not have any sensation of motion. They can neither feel nor see that the earth is orbiting the sun. How, then, does anyone know that the earth is

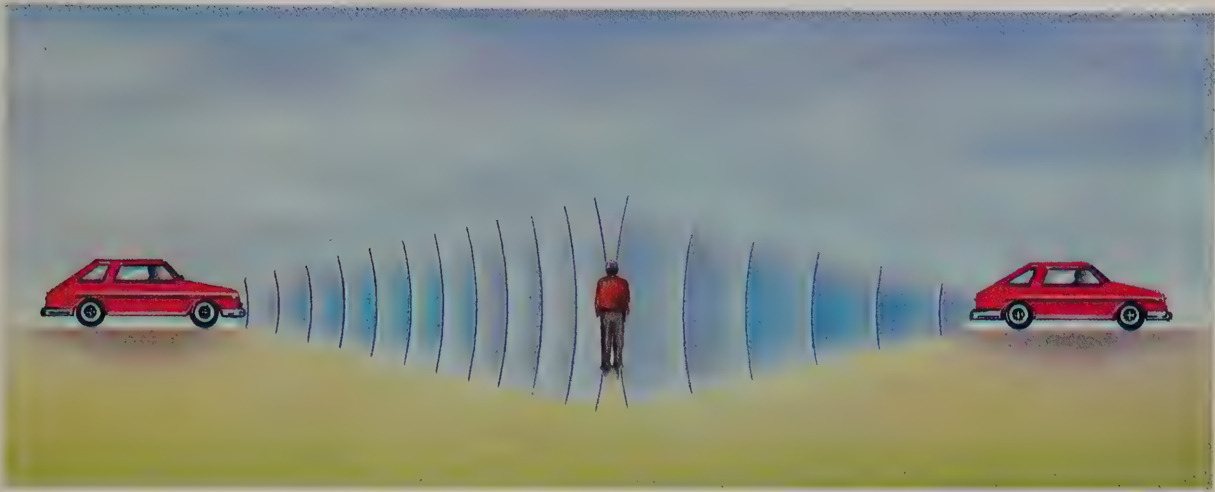


Figure 3-23. How can you tell from the sound of a car horn whether the car is moving toward you or away from you?

traveling in such a huge orbit? Is there any evidence for the earth's revolution?

One bit of evidence known to astronomers today is the Doppler effect on starlight. If you've ever listened to the horn of a speeding car, then you may have heard the Doppler effect on sound waves. Think about that sound for a moment. How can you tell whether the car is coming toward you or traveling away from you? One clue is loudness. But the other clue is the **Doppler effect.** As the car speeds toward you, the sound of the horn appears to have a higher pitch (frequency) than when it speeds away from you. As the car passes you, the pitch of the horn suddenly seems to get lower.

The Doppler effect is named after Christian Doppler, an Austrian physicist who first described it in 1842. The sound waves from a source racing toward you are crowded together. This causes them to have a higher pitch. When the car moves away from you, the sound waves spread out more, causing a lower pitch. Sound waves that are closer together have a higher frequency and therefore a higher pitch than waves that are farther apart.

Like sound, light also travels in waves. Light waves are also affected by motion. With a car, locomotive, jet plane, or other moving source of noise, the Doppler effect causes a change in sound waves. With starlight, the Doppler effect causes a change in the light waves traveling from the star.

Activity Graphing the Altitude of the Sun

Materials

altitude-of-sun data table
graph paper
pencil
colored pencil

Purpose

To graph the altitude of the sun throughout the year.

What to Do

1. Working only from the data in the data table, graph the altitude of the noonday sun for the days given in the table.
   SAFETY NOTE: *For this activity, use only the data in the data table. Never attempt to look directly at the sun. To do so is dangerous to your eyesight.*
2. After you have plotted the points on the graph, connect the plots with a smooth line.
3. Mark an x on the graph with colored pencil for the following dates: March 21, June 21, September 23, and December 21. Label each of these dates.

Questions

1. On what date is the altitude of the sun the highest? the lowest?
2. What is the cause of the change in altitude?
3. Between which two of the x's is the altitude of the sun the highest? the lowest?

Conclusion

What do the graph and the data table tell you about the sun's altitude and the seasons on earth?

Data Table Altitude of the sun at noon—Cincinnati, Ohio, 40° North latitude

Date	Altitude of Sun	Date	Altitude of Sun	Date	Altitude of Sun	Date	Altitude of Sun
Jan 10	25°54′	Apr 10	55°36′	Jul 10	70°21′	Oct 10	41°42′
20	27°41′	20	59°12′	20	68°50′	20	37°59′
30	30°06′	30	62°29′	30	66°44′	30	34°31′
Feb 10	33°21′	May 10	65°23′	Aug 10	63°50′	Nov 10	31°07′
20	36°45′	20	67°47′	20	60°45′	20	28°31′
Mar 1	40°27′	30	69°38′	30	57°20′	30	26°30′
10	43°32′	Jun 10	70°57′	Sep 10	53°17′	Dec 10	25°10′
20	48°32′	20	71°26′	20	49°27′	20	24°35′
30	51°25′	30	71°14′	30	45°34′	30	24°46′

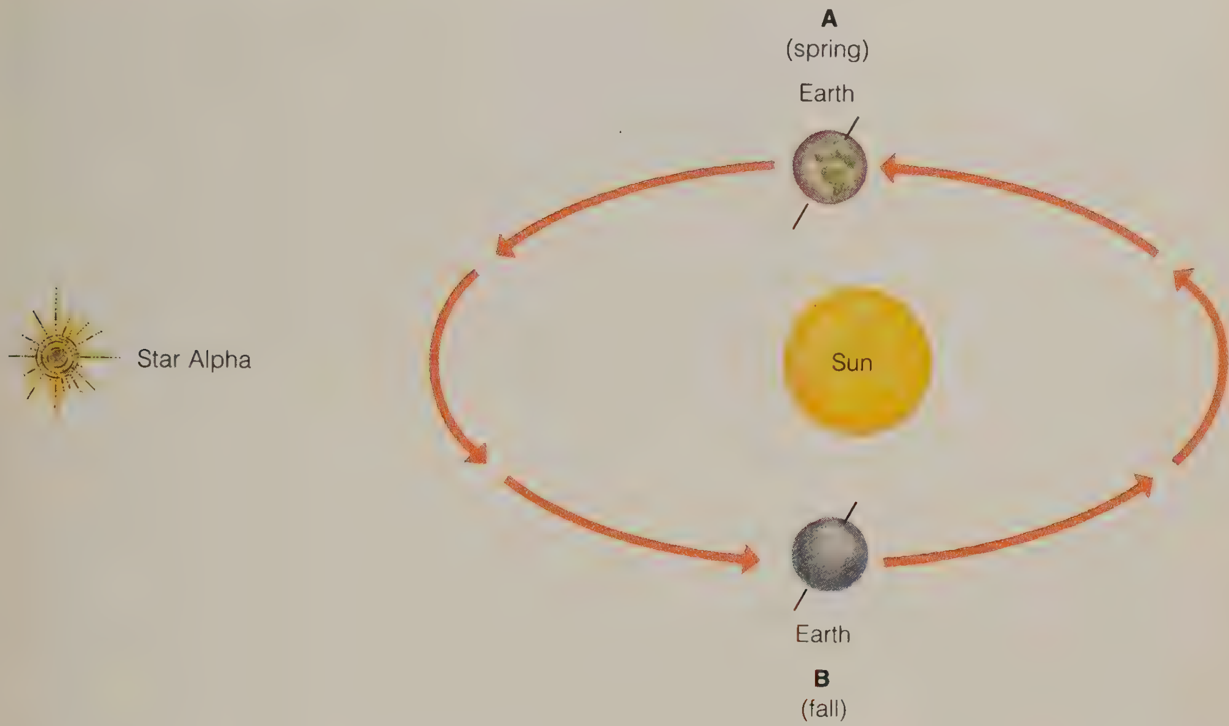


Figure 3-24. At Position A, the earth is traveling toward star Alpha. At Position B, the earth is traveling away from star Alpha. How are astronomers able to know that this is happening?

Figure 3-24 shows how an observer on the earth can use the Doppler effect to demonstrate that the earth is revolving around the sun. The earth at Position A is traveling toward star Alpha. Six months later, the earth at Position B is moving away from star Alpha. The light waves from star Alpha that reach the earth at Point A are not exactly the same as the light waves that reach the earth six months later at Point B. The light waves that reach the earth at Point A have a higher frequency than the light waves that reach the earth at Point B.

Astronomers can use this change in the frequency of light waves to measure the velocity of the earth in relation to a star. In Figure 3-24, star Alpha was used merely as an example. To chart the course and velocity of the orbiting earth, readings based on many other stars are also needed.

Check yourself

1. How can you use the Doppler effect to tell whether the horn of a speeding car is approaching you or traveling away from you? Why does this happen?
2. How can the Doppler effect be used to demonstrate that the earth is moving? Which earth motion is demonstrated—revolution or rotation?

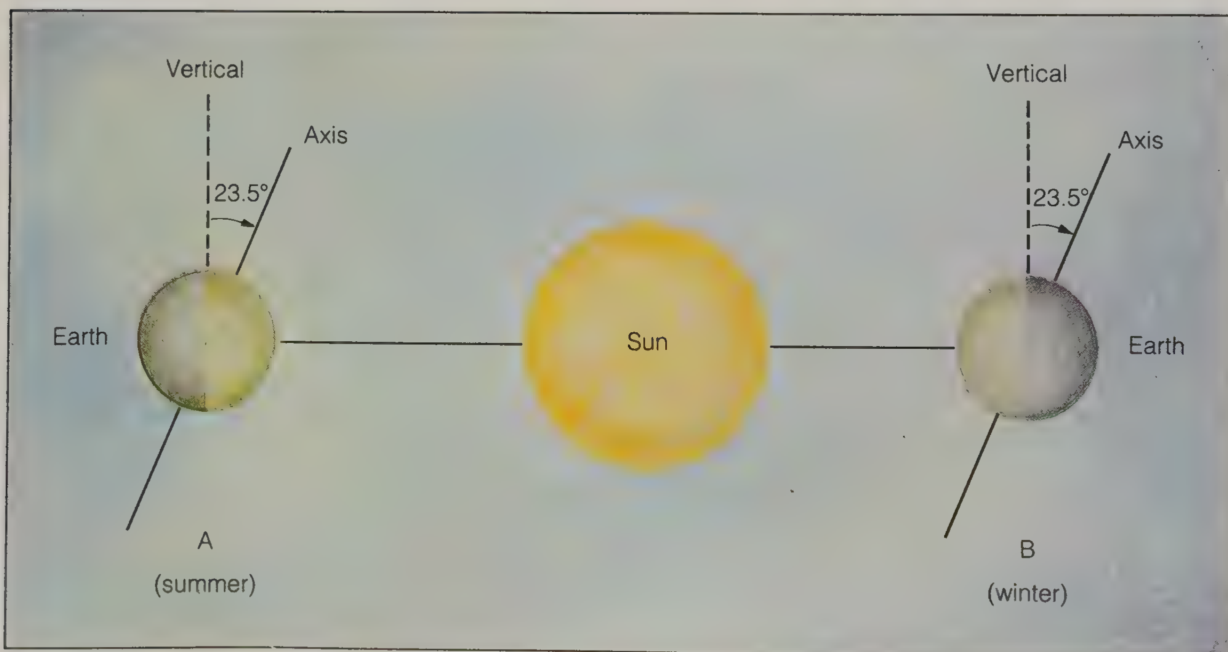
The inclination (tilt) of the earth's axis

Perhaps you've already noticed something about the earth's axis in any of the illustrations in this section of Chapter 3. It has not been pictured as straight up and down. That is because the earth's axis is tilted 23.5° off the vertical. This tilt of the earth's axis is called **inclination.**

Look at Figure 3-25. The line from A to B represents the level, or plane, of the earth's orbit as it travels around the sun. As the earth travels in orbit around the sun, its axis is tilted 23.5° off the vertical to the plane of its orbit. It is important to know that the earth's axis has a tilt, or an inclination, of 23.5° off the vertical. It is also important to know that the direction of the inclination remains the same, regardless of the earth's position anywhere along its orbit.

Two observations are offered as evidence of the tilt and the unchanging direction of the earth's axis. The position of Polaris is evidence that the earth's axis points in the same direction all year long. On any night of the year, Polaris can be found on an imaginary line that continues out from the end of the earth's northern axis.

Figure 3-25. The earth's axis is tilted off the vertical to the imaginary line from A to B. What does the line AB represent?



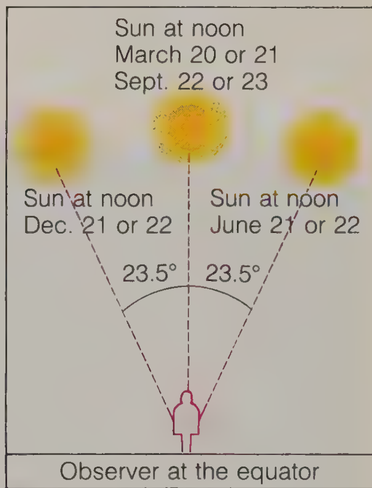
Altitude Readings of the Sun at the Equator				
Time	Date	Place	Altitude of Sun	Deviation from Vertical (See also Fig. 3-26.)
noon	March 20 or 21	equator	90°	0°
noon	June 21 or 22	equator	66.5°	23.5°
noon	Sept. 22 or 23	equator	90°	0°
noon	Dec. 21 or 22	equator	66.5°	23.5°

Table 3-2. At what two times of the year is the sun directly overhead at the equator?

For evidence that the earth is tilted on its axis, consider Table 3-2 and Figure 3-26. They show what happens to the altitude of the sun at the equator over the course of a year. At the equator, the altitude of the sun shifts from the vertical to a maximum deviation of 23.5° twice a year. After each maximum deviation, the sun's altitude then returns to the vertical.

How, you might ask, does this deviation from the vertical indicate that the earth's axis is tilted? Return to Figure 3-25 for a minute. Imagine what would happen if the earth's axis were shifted to the vertical. The sun would then be directly overhead at the equator on every day of the year. There would be no deviation from the vertical at the equator. That is why a deviation from the vertical at the equator is evidence that the earth's axis is not vertical to the plane of its orbit.

Figure 3-26. The altitude of the sun at the equator deviates from the vertical. If the earth's axis were not tilted, the altitude of the sun at the equator would be 90° every day of the year.



Check yourself

1. What evidence indicates that the earth's axis is tilted?
2. List two evidences that the earth's axis is inclined 23.5°.
3. What evidence indicates that the direction of the earth's axis is unchanging?
4. What would happen if the earth's axis were vertical?

The seasons

If you were asked to compare the seasons, you would probably mention that in summer it is warmer than it is in winter. You might also mention that in summer there are many more hours of daylight. Changes in temperature and in length of daylight are features that are associated with the seasons.

What are three causes that produce the seasons?

As you will see from Figure 3-27, there are three causes for the changes in temperature and in day length that produce the seasons. These causes are 1) the inclination of the earth's axis, 2) the revolution of the earth around the sun, and 3) the unchanging direction of the earth's axis.

Look at the earth in the December 22 or 23 position in Figure 3-27. Note first of all that in December the North Pole is tilted away from the sun. This causes the strongest rays from the sun, or those rays that are most direct (vertical), to strike the earth south of the equator. On December 22-23, the vertical rays from the sun strike an imaginary circle called the **Tropic of Capricorn,** which is at 23.5 South latitude. At this time, the Southern Hemisphere begins its first day of summer and the Northern Hemisphere begins its first day of winter.

Consider the sun's rays in December. The most energy from

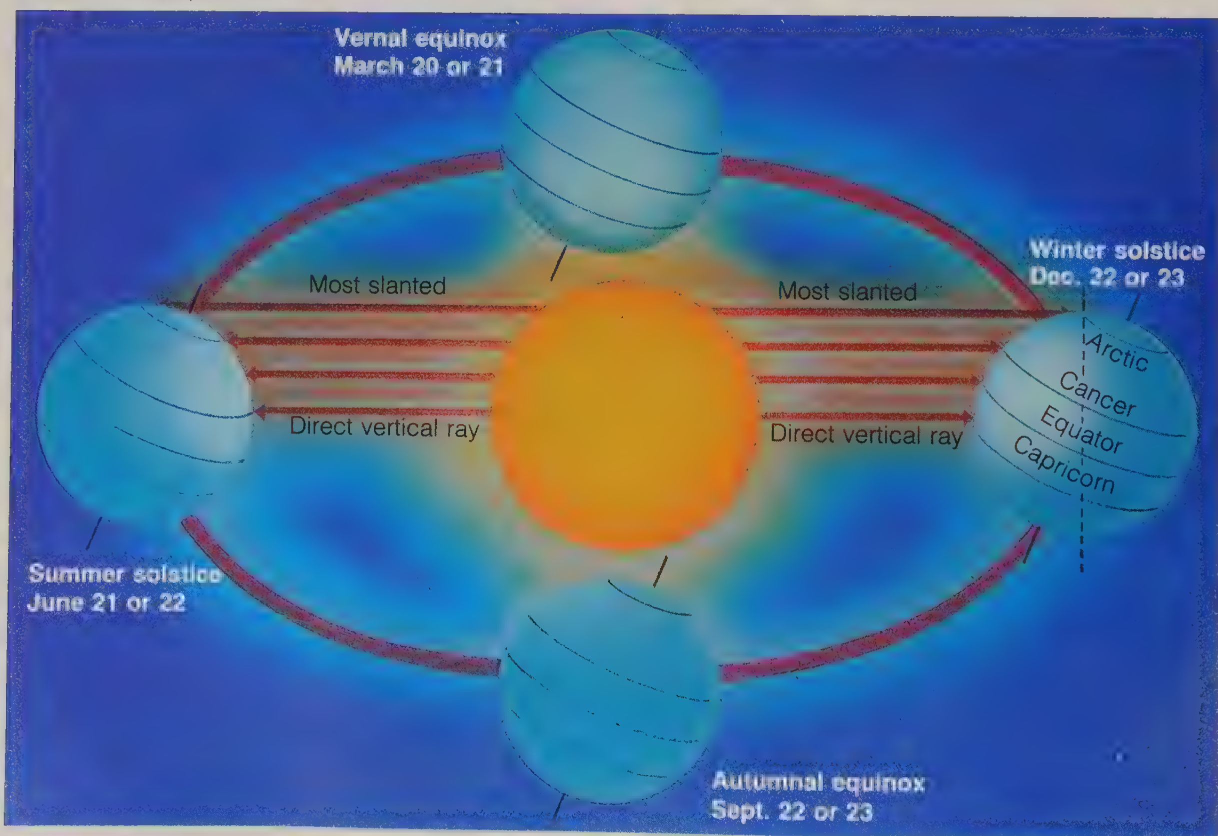


Figure 3-27. This diagram illustrates three causes of seasons on the earth: 1) the earth's inclination, 2) the earth's revolution, and 3) the unchanging direction of the earth's axis.

the sun is reaching the earth in direct vertical rays at the Tropic of Capricorn. The altitude of the sun at the Tropic of Capricorn at noon on December 22 or 23 is 90°. But in the Northern Hemisphere, the earth is receiving much weaker, slanted rays from the sun.

Now consider day length in December. Find the **Tropic of Cancer,** which is at 23.5° North latitude. Then imagine where the vertical light-dark line crosses the earth in December. (Compare Figure 3-25 on page 154 with Figure 3-27 on page 156.) South of the Tropic of Cancer, days are longer than nights. But north of the Tropic of Cancer, nights are longer than days. In fact, you can see that there is no sunlight at all inside the Arctic Circle on December 22 or 23. At that time, the sun never rises inside the Arctic Circle. The night is twenty-four hours long.

At what latitude does the Tropic of Cancer circle the earth?

At the South Pole, just the opposite is happening. Inside the Antarctic Circle on December 22 or 23, the sun never sets. At that time, the day is twenty-four hours long at any point between 66°30′ and 90° South latitude.

Now look at the earth in its June 21 or 22 position. In the Southern Hemisphere, it is winter. In the Northern Hemisphere, it is summer. Direct vertical rays from the sun are striking the Tropic of Cancer, which is at 23.5° N latitude. North of the Tropic of Cancer, days are longer than nights. And inside the Arctic Circle there are twenty-four hours of daylight.

As shown in Figure 3-27, June 21 or 22 and December 22 or 23 mark the periods when the sun's direct vertical ray reaches its farthest points north or south of the equator. These two times of the year are known as **solstices,** from the Latin words for the sun stands still. In the Northern Hemisphere, the solstice in June marks the beginning of summer and is known as the summer solstice. The December solstice, which marks the beginning of winter in the Northern Hemisphere, is known as the winter solstice.

There are two times in the year when the sun's vertical rays reach the farthest point north or south of the equator. What are these two times of the year called?

On March 20 or 21 and on September 22 or 23, the sun's direct vertical rays strike the equator. At those times, days and nights are of equal length all over the earth. And the seasons called spring and fall begin.

These two times of the year, when the sun crosses the equator on its way to the Tropic of Cancer or the Tropic of Capri-

Activity Comparing Day Lengths

Materials

sunrise-sunset data table

pencil and paper

Purpose

To see how day lengths compare at different latitudes and at different times of the year.

Data Table								
	0° Latitude		30° North		40° North		50° North	
	Sunrise	Sunset	Sunrise	Sunset	Sunrise	Sunset	Sunrise	Sunset
Mar 21	6:05	6:07	6:03	6:12	6:02	6:13	6:00	6:14
June 21	5:58	6:01	4:59	7:32	4:31	7:32	3:50	8:13
Sep 23	5:57	6:03	5:49	5:55	5:48	5:56	5:48	5:56
Dec 21	5:56	6:01	6:52	5:05	7:19	4:39	7:56	4:01

Day Length in Hours (h) and Minutes (min)								
	0° Latitude		30° North		40° North		50° North	
	h	min	h	min	h	min	h	min
Mar 21	12 h	2 min						

What to Do

1. Make a data table for day lengths similar to the sample on this page, but add spaces for June 21, September 23, and December 21.
2. Using the times on the data table for sunrise-sunset, calculate the length of daylight (hours and minutes) for each date and latitude. Record the day lengths on your chart.

Questions

1. At what dates is there an almost equal amount of daylight and darkness at all latitudes?
2. At what latitude is the number of hours of daylight and darkness almost the same for the entire year?
3. Examine the amount of daylight on June 21 at each latitude given for the Northern Hemisphere. What happens to the length of daylight as the latitude increases?
4. Examine the hours of daylight for December 21. What happens to day length as latitude increases?
5. How many hours of daylight do you think there are at 90° North latitude on June 21? on December 21?
6. How would your chart look if you did this for the same dates and latitudes in the Southern Hemisphere?

Conclusion

A day is 24 hours long. But as you can see from your completed data table, the number of hours of daylight varies. Based on your data table, what two things cause this difference in the number of hours of daylight?

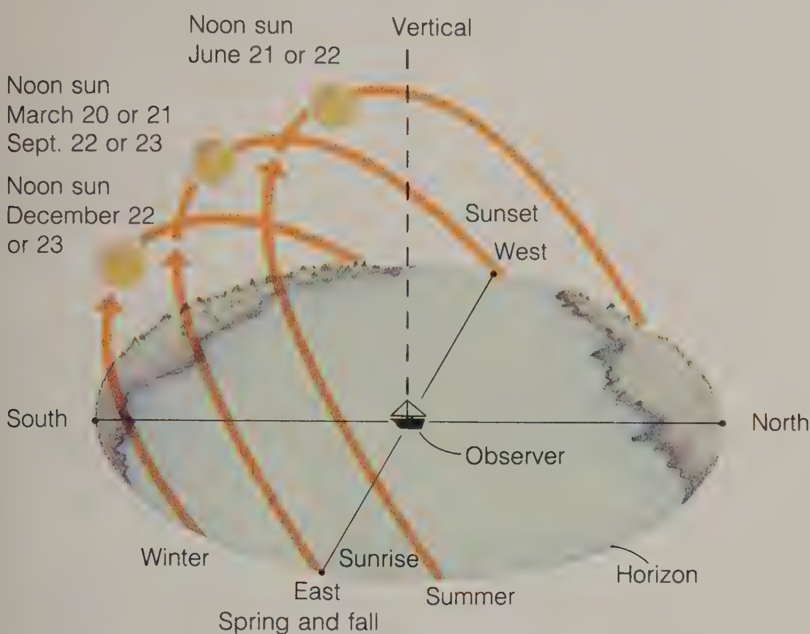


Figure 3-28. The strongest rays from the sun are those that are most direct, or vertical. On what day of the year are the sun's rays most nearly overhead for the observer in the diagram?

corn, are known as the **equinoxes.** They are called equinoxes, from the Latin words for equal night, because at these two times of the year night and day are of equal length everywhere on the earth. The equinox that marks the beginning of spring is called the vernal equinox. The equinox that marks the beginning of fall is called the autumnal equinox.

What is a name for the equinox at the beginning of spring?

Near the equator, there is little change in temperature. The places near the equator receive the sun's rays more nearly directly the year round. And the amounts of daylight and darkness are almost equal all year. As a result, temperatures near the equator remain hot throughout the year.

At the higher latitudes, however, seasonal changes are much greater. Look at Figure 3-28. It shows the noontime positions of the sun at the summer solstice, the winter solstice, and the equinoxes for an observer in the Northern Hemisphere. In summer, when the sun's rays are more nearly overhead and days are longer, average temperatures are higher than in winter. In winter, the sun's rays are more slanted and the hours of sunlight are fewer. This results in much lower average temperatures for locations in the Northern Hemisphere.

Check yourself

1. How do the Tropic of Cancer and the Tropic of Capricorn relate to the earth's inclination on its axis?
2. Explain the three causes for the seasons on the earth.

Activity Simulating the Seasons on Earth

Materials

crayon
light source
plastic-foam ball, 5-7 cm in diameter
knitting needle

Purpose

To show how the revolution of the earth and the inclination of the earth's axis cause the seasons.

What to Do

1. Draw a circle around the middle of the plastic-foam ball. This represents the equator.
2. Place a knitting needle through the center of the ball at a 90° angle to the equator. The knitting needle represents the earth's axis.
3. Tilt the knitting needle to an angle of about 23.5° to represent the inclination of the earth's axis. (Upright is 90°; halfway between the horizontal and upright is 45°; move halfway again toward the upright and you are close to 23.5°.)
4. Examine Figure 3-27 on page 156. Place your model earth in the position of the autumnal equinox in relation to your light source, which represents the sun. Make sure that the axis of your model is pointing in the right direction. Note how much of your model earth is in daylight.
5. Slowly turn the needle so that the model earth makes one complete rotation. Compare the daylight with the darkness.
6. Move the model earth to the next position, the winter solstice. Remember not to change the direction of the earth's axis. The north end of the axis should always point in the same direction, as in Figure 3-27.
7. As you move your model slowly from the September position to the December position, observe what happens to the daylight and the darkness.
8. Turn the earth one full turn in the winter solstice position. Look for a place that receives sunlight all the time. Look for a place that receives no sunlight.
9. Move your model to the position of the vernal equinox. Compare the light-dark pattern to that of the other positions you've tried.
10. Move your model to the position of the summer solstice. Compare the North Pole at the summer solstice with the North Pole at the winter solstice. Move your model back to the position of the winter solstice, if you need to, for this comparison. Be sure the axis of your model is pointing in the right direction.

Questions

1. At the autumnal equinox position, how much of your model earth is in daylight? Is the earth lighted from pole to pole?
2. At the autumnal equinox, is every place on earth getting an equal amount of sunlight after one turn?
3. What happens to the daylight and the darkness as you move your model from the September to the December position?
4. At the winter solstice position, is there any place that receives sunlight all the time? Where is it?
5. At the vernal equinox position, is the pattern of light-dark similar to the pattern in any other position? Which one?
6. What is the difference between the North Pole at the winter solstice and the North Pole at the summer solstice?

Conclusion

How does this activity show that the seasons are caused by the revolution of the earth around the sun, by the inclination of the earth's axis, and by the fact that the earth's axis always points in the same direction?

The time of the year

How is time related to change?

Time and change are closely related. It is change that makes us aware of time. It is also change that provides us with a means of measuring time. The changing of the seasons, the changing shapes of the moon, and the changing of the hour hand on a clock are but a few of the changes that let us measure time.

Today we have watches and clocks, which are mechanical timekeepers. These and other mechanical timekeepers have been in existence for only a relatively short period of time. But there are also natural timekeepers which are as old as the earth

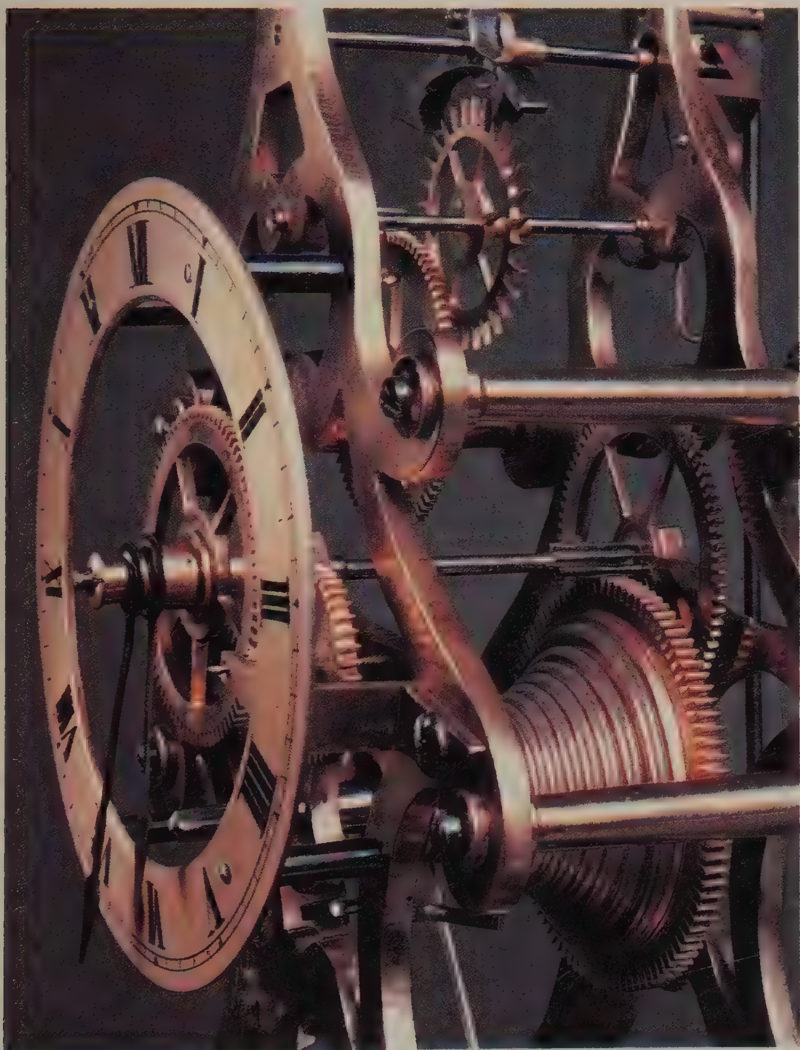


Figure 3-29. Clocks, watches, and other kinds of mechanical timekeepers have been in existence for only a relatively short period of time. What are some natural timekeepers that are as old as the earth itself?

Library research

There are many calendars in the world. You have read about the Julian and Gregorian calendars. Find out about the Chinese calendar or the Hebrew calendar. Upon what are they based? Are there any other new proposals for calendars?

itself. These natural timekeepers include the rotation of the earth, the revolution of the earth around the sun, and the changing shapes of the moon.

Early people used the changing shapes of the moon to keep track of time. The time from one full moon to the next full moon was called a month. This period of time, from one full moon to the next, is twenty-nine and a half days. But twelve months of that length totaled only 354 days in the year. This did not agree with the length of a year based on the sun's changing position in the sky.

In 46 B.C., the Roman emperor Julius Caesar devised a system that was not based on the moon. Caesar determined the year to be 365¼ days. To account for these ¼ days, it was decided to add an extra day to the month of February every fourth year. The year in which an extra day is added to February is known as a **leap year.**

The year as measured out into weeks and months by Julius Caesar is known as the Julian calendar. But even with the year at 365¼ days, the Julian calendar was not entirely accurate. It was off by 11 minutes and 14 seconds per year. Eleven minutes and a few seconds may not seem like much. But by the year 1582 the vernal equinox had moved from March 21 to March 11. In that year, Pope Gregory ordered the calendar to be corrected. Ten days were dropped from October of 1582 so that the vernal equinox would once again occur around March 21, beginning in 1583. To accomplish this, October 5, 1582, became October 15, 1582.

The calendar as changed by Pope Gregory is known as the Gregorian calendar. To account for the extra eleven minutes per year, it was decided that century years like 1800 and 1900 would be leap years only if they could be divided evenly by four hundred. That means that the year 2000, for instance, will be a leap year, but the year 2100 will not be a leap year. This eliminates three leap years every four hundred years and is enough to keep the Gregorian calendar in agreement with the equinoxes and the seasons.

The Gregorian calendar is used widely throughout the world today. With the Gregorian calendar, the day of the week and the day of the month change from year to year. Your birthday, for example, falls on a different day of the week each year.

January	February	March	April	May	June	
S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	
1 2 3 4 5 6 7	1 2 3 4	1 2	1 2 3 4 5 6 7	1 2 3 4	1 2	
8 9 10 11 12 13 14	5 6 7 8 9 10 11	3 4 5 6 7 8 9	8 9 10 11 12 13 14	5 6 7 8 9 10 11	3 4 5 6 7 8 9	
15 16 17 18 19 20 21	12 13 14 15 16 17 18	10 11 12 13 14 15 16	15 16 17 18 19 20 21	12 13 14 15 16 17 18	10 11 12 13 14 15 16	
22 23 24 25 26 27 28	19 20 21 22 23 24 25	17 18 19 20 21 22 23	22 23 24 25 26 27 28	19 20 21 22 23 24 25	17 18 19 20 21 22 23	
29 30 31	26 27 28 29 30	24 25 26 27 28 29 30	29 30 31	26 27 28 29 30	24 25 26 27 28 29 30	W

July	August	September	October	November	December	
S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	
1 2 3 4 5 6 7	1 2 3 4	1 2	1 2 3 4 5 6 7	1 2 3 4	1 2	
8 9 10 11 12 13 14	5 6 7 8 9 10 11	3 4 5 6 7 8 9	8 9 10 11 12 13 14	5 6 7 8 9 10 11	3 4 5 6 7 8 9	
15 16 17 18 19 20 21	12 13 14 15 16 17 18	10 11 12 13 14 15 16	15 16 17 18 19 20 21	12 13 14 15 16 17 18	10 11 12 13 14 15 16	
22 23 24 25 26 27 28	19 20 21 22 23 24 25	17 18 19 20 21 22 23	22 23 24 25 26 27 28	19 20 21 22 23 24 25	17 18 19 20 21 22 23	
29 30 31	26 27 28 29 30	24 25 26 27 28 29 30	29 30 31	26 27 28 29 30	24 25 26 27 28 29 30	W

Table 3-3. What do the W at the end of June and at the end of December stand for?

A new calendar called the World Calendar has been suggested as a replacement for our present calendar. Table 3-3 shows the days of the year according to the proposed World Calendar. Some things to note about the World Calendar:

1. The W at the end of December stands for Year End Day. The World Calendar proposes 91 days for each quarter of the year. This totals only 364 days a year. The 365th day, Year End Day, would follow December 30 each year and would be a world holiday.

2. The W at the end of June stands for Leap Year Day and would occur only during a leap year. Leap Year Day would also be a world holiday.

3. January 1 on the proposed World Calendar would always be on a Sunday. All other calendar dates would also fall on the same day of the week, year after year.

Check yourself

1. List three natural timekeepers. What period of time does each indicate?
2. What effect did the vernal equinox have on the calendar as we know it today?

Careers Astronomer / Instrumentation Technician

By means of the computer, this astronomer is able to study data received through the observatory's powerful telescope.

Astronomer Through the ages, astronomers have been responsible for new, exciting, and at times startling theories. The geologist, the meteorologist, and the oceanographer can tell us much about the earth we live on. But it is the astronomer who helps us to see the earth in relation to the countless objects that surround us in space.

Because astronomers study the sun, stars, planets, and outer space, their area of investigation is much more open to theory and to the need for very powerful and reliable instruments. The information that astronomers learn about the various stars, planets, galaxies, and nebulae is obtained by analyzing light waves and radio waves that are being emitted from objects in space.

Regardless of the career you finally choose, you can always pursue an interest in astronomy and learn more about quasars and pulsars and black holes. But astronomy as a career is a very limited area. There are not many job openings for astronomers.

Most astronomers teach in colleges and universities or work for the aerospace industry. To prepare for a career in astronomy, or even to be able to appreciate the latest findings of astronomers, take as many courses in mathematics and the physical sciences as you can.

An instrumentation technician is responsible for seeing that needed equipment is kept in good repair.

Instrumentation Technician Technicians are persons who perform many tasks that help the specialist. Scientists, astronomers, and navigators are desperately in need of instrumentation technicians, who assist specialists in using instruments for data gathering, data analysis, and record keeping. Instrumentation technicians also see to it that the various instruments, machines, and other needed equipment are kept in good running order.

To get a job as a technician, it would be necessary to have a high school education with some basic courses in science, mathematics, and English. It would also be helpful if you had good manual dexterity, some mechanical aptitude, and the ability to organize data. Technicians frequently get on-the-job training or attend technical schools or programs.

Section 3 Review Chapter 3

Check Your Vocabulary

circumpolar stars	orbit
Doppler effect	revolution
equinox	solstice
inclination	Tropic of Cancer
leap year	Tropic of Capricorn

Match each term above with the numbered phrase that best describes it.

1. The motion of the earth as it travels around the sun
2. The path that an object follows as it travels around another object
3. Stars always found near the poles
4. Changes in sound waves or light waves as the source of the waves moves toward or away from an observer
5. The tilt of the earth's axis
6. An imaginary line that circles the earth at 23.5° South latitude
7. An imaginary line that circles the earth at 23.5° North latitude
8. The time of the year when the sun's vertical rays reach farthest north or south
9. The time of the year when the sun crosses the equator on its way to the Tropic of Cancer or the Tropic or Capricorn
10. The year in every four years in which an extra day is added to February

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The Doppler effect on starlight is offered as evidence of the earth's _?_.
   a) revolution c) deviation
   b) rotation d) inclination
2. The earth travels in orbit about _?_.
   a) 1° a day c) 23.5° a month
   b) 15° a day d) 23.5° a week
3. The _?_ is tilted 23.5° off the vertical.
   a) equator c) earth's orbit
   b) earth's axis d) star Alpha
4. At the end of December, all of the Southern Hemisphere is in _?_.
   a) darkness c) summer
   b) light d) winter
5. Julius Caesar and Pope Gregory are associated with changes in _?_.
   a) watches and clocks
   b) the calendar
   c) the seasons
   d) light and sound waves

Check Your Understanding

1. Draw a simple diagram that shows how the same constellation can be part of the nighttime sky in winter and the daytime sky in summer.
2. What is the cause of the Doppler effect?
3. On August 1, which is longer at the Tropic of Cancer—day or night? Explain.
4. Draw a simple diagram that shows why there is no sunlight inside the Arctic Circle on December 22 or 23.
5. Describe the equinoxes and solstices in terms of dates and where the vertical rays of the sun are striking the earth. What does *equinox* mean? What does *solstice* mean?

Chapter 3 Review

Concept Summary

Earth motions, which can refer to any movements of the earth, include specifically the earth's rotation on its axis and the earth's revolution around the sun.

- ☐ The motions of the sun, moon, and stars across the sky are evidence that either they or the earth is moving.
- ☐ The sum total of movements across the sky is most easily explained if the earth is considered to be moving.

The earth's rotation is the turning of the earth on its axis once a day.

- ☐ The Foucault pendulum demonstrates that the earth is in motion.
- ☐ The earth's rotation explains day and night, hourly changes in the night sky, and the deflection of objects traveling above the earth's surface.

The earth's axis is the imaginary line around which the earth spins.

- ☐ The North and South Poles are sometimes considered as the points where the earth's axis passes through the earth's surface.
- ☐ If continued out beyond the North Pole, the earth's axis extends toward Polaris, the North Star.

The earth's revolution is the orbiting of the earth around the sun once a year.

- ☐ Seasonal changes are most easily explained by the earth's revolving around the sun.
- ☐ The Doppler effect on starlight is offered as evidence that the earth orbits the sun.

The earth's inclination is the tilting of the earth's axis 23.5° off the vertical.

- ☐ The earth's axis always points in the same direction, toward Polaris (or away from Polaris, if considered in reverse).
- ☐ The fact that the sun's direct rays do not strike the earth's surface at the equator year round is evidence that the earth's axis is tilted.

Putting It All Together

1. What are some models that can be used to help observe the night sky?
2. Make a diagram that shows that the azimuth of southwest is 225°.
3. How many degrees does the earth rotate in 24 hours? in 1 hour? in 3 hours?
4. A constellation is observed at the same time and from the same location each night for a month. After one month, what appears to have happened? Why?
5. From the information given, identify the latitude of an observer in each situation.

Date	Sun's Altitude	Date	Sun's Altitude
Mar 21	90°	Mar 21	0°
June 21	90°	Dec 21	no sun visible
Sept 21	90°	Sept 23	66.5°
Dec 21	90°		

6. What would happen if the earth's axis was upright rather than inclined?
7. Draw a diagram that shows how the earth's position on June 21 causes warm weather in the Northern Hemisphere.
8. If a person starts out in New York City at noon and travels west at the rate of 15° per hour, what time will it be when the person arrives in San Francisco four hours later?
9. It is noon in your time zone. What time is it in the time zone to your east? to your west?
10. Define natural time, mechanical time, apparent solar time, mean solar time, Greenwich mean time, daylight-saving time.

Apply Your Knowledge

1. Make believe you deliver newspapers. You toss them onto doorsteps as you ride along on your bicycle. In order for a newspaper to

land on a doorstep from your bicycle, when should you toss it? Why?
2. Does the sun always rise directly in the east? Explain your answer.
3. Does the horizon change with respect to an observer on the surface of a rotating earth? Explain your answer.
4. When it is 1:00 a.m. Monday Greenwich mean time, what time (eastern daylight-saving time) and day is it in New York (which is located at 75° W longitude)?
5. If you were traveling around the world, how many times would you have to reset your clock or watch? Why? Under what circumstance would you set the clock ahead each time? Under what circumstance would you set the clock back each time?

Find Out on Your Own

1. With binoculars or a telescope, find the Pleiades in the constellation Taurus. Make a drawing of the star group and explain what you saw to the class.
2. You can make your own planetarium with a lamp and a tin can. Many science books with projects tell how. You can actually project constellations. You can also make a slide projector with a shoe box.
3. Keep track of sunrise and sunset for 2–3 weeks. This can be obtained from a newspaper or almanac. Are the lengths of daylight getting longer or shorter? Is the amount of time from sunrise to sunrise always the same? Account for this observation.
4. Sundials were used by ancient Egyptians to indicate the time of day. Build a sundial and demonstrate how it works.
5. Invent a calendar of your own based on the motions of the moon. Give the days and months appropriate names. Explain your calendar to the class.

Reading Further

Adler, Irving. *The Stars: Decoding Their Messages*. New York: Crowell, 1980.

A fine explanation of how astronomers get their information about stars, galaxies, and space.

Ford, Adam. *Spaceship Earth.* New York: Lothrop, Lee and Shepard, 1981.

Topics include solar system, stars, constellations, light, and gravity. Easy reading with 40 pages of illustrations.

Hamer, Martyn. *The Night Sky*. New York: Watts, 1983.

An informative, interesting account of the constellations, sky, and stars. The illustrations are excellent.

Levitt, I. M., and Roy K. Marshall. *Star Maps for Beginners.* New York: Simon and Schuster, 1983.

Twelve full-page star charts showing the night sky for each month of the year. Clear descriptions make this book outstanding for a beginner stargazer.

Provenzo, Eugene F., Jr., and Asterie Baker Provenzo. *Rediscovering Astronomy.* LaJolla, CA: Oak Tree, 1980.

Shows how to make and use your own astrolabe, quadrant, sextant, and telescope. Helps you to understand the creative process involved in astronomical discoveries.

Simon, Seymour. *Look to the Night Sky: An Introduction to Star Watching*. New York: Penguin, 1983.

An enjoyable, usable guide to stargazing. Includes descriptions of the major constellations, the moon, planets, meteors, and comets.

Snowden, Sheila. *The Young Astronomer.* Tulsa, OK: Educational Development Corp., 1983.

An excellent first reference book and guide to the universe. Outstanding illustrations.

Chapter 4

Beyond the Earth

Section 1
The Moon

The development of various instruments has greatly affected our knowledge of the earth we live on. Because of instruments, we are able to study particles of matter far too small to be detected in any other way. Because of instruments, we are able to travel to areas of the earth's surface that are far below its seas or far above its plains. Because of instruments, it has been possible for astronauts to set foot on the moon, the earth's natural satellite and its closest neighbor.

Section 2
The Solar System

The earth can be considered as an object in itself, with its own processes and cycles. But such a consideration would be incomplete. The earth is merely one of very many objects in space. Our understanding of the earth in relation to these other objects, and particularly in relation to the sun, will necessarily affect the way in which we consider individual aspects of the earth on which we live.

Section 3
The Stars

How far is far? Think of the things that used to be far away. At one time, the other side of a river or lake or forest was far away. As means of transportation developed, faraway places like the other side of a continent or the other side of an ocean or the other side of even the earth itself ceased to be distant.

Modern technology continues to expand our knowledge and our understanding of what is beyond us and beyond the earth and even beyond the solar system and the galaxy of which we are a part. Modern technology continues to expand our understanding of even space and time.

A system is a grouping or arrangement of parts that are interrelated in some way. Systems like the galaxy (NGC 598 in Triangulum) on the facing page are very large. When you consider the earth and its processes, what other kinds of systems can you think of?

The Moon Section 1

Section 1 of Chapter 4 is divided into three parts:

Characteristics of the moon

Phases and eclipses of the moon

Information from the *Apollo* program

Figure 4-1. This closeup view of an astronaut's footprint in the lunar soil was taken on July 20, 1969. From the photograph, what can you tell about the moon's surface?

Figure 4-2. The landing module *Intrepid*, part of the *Apollo 12* expedition, begins its descent to the lunar surface. What does the word *lunar* mean?

In 1969, millions of people witnessed what was originally thought to be "impossible." People from the earth walked on the surface of the moon. In the years following, from 1969 to 1972, television screens around the world broadcasted live the greatest exploration of human history as six *Apollo* spacecraft landed on the moon.

Characteristics of the moon

Long before astronauts landed on the surface of the moon, information had been obtained about the moon without even leaving the earth's surface. Although most of this information remained unchanged after the **lunar** (moon) landings of *Apollo* spacecraft, vast amounts of new information were returned to the earth concerning the nature and evolution of the moon. (The word *lunar* comes from *luna,* the Latin word for the moon.)

The moon is the earth's only natural **satellite.** (A satellite is an object that revolves around another body. A satellite is smaller.) Many artificial satellites, however, now travel around the earth. All of these artificial satellites were launched from the earth. The first of these *(Sputnik I)* was launched in 1957.

Activity A Way to Calculate the Diameter of the Moon

Materials

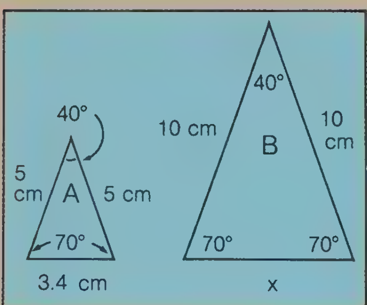
dime, penny, nickel
masking tape
meter stick or metric tape measure

Purpose

To use indirect measurement to calculate the diameters of a classroom clock and the moon.

What to Do

1. Assume that you must calculate the diameter of the classroom clock but cannot measure it directly with the meter stick.
2. A helpful method of direct measurement uses similar triangles, which are triangles having sides in proportion. Look at the diagram of two triangles.



What is the length of x in triangle B? It is found by setting up a proportion for the similar triangles, as follows:

$$\frac{5}{10} = \frac{3.4}{x}$$
$$5x = 10 \times 3.4$$
$$5x = 34$$
$$x = 6.8 \text{ cm}$$

3. You are now ready to calculate the diameter of the clock on the wall. Measure the distance from the wall to the point where you are standing. It is good to be across the room and directly opposite the clock.
4. Measure the diameter of your coin. Close one eye. Hold the coin at arm's length between your open eye and the clock. Move the coin toward your eye until it exactly covers the clock. Have a partner take the meter stick and measure the distance from your eye to the coin.
5. You now have three measurements and can calculate the diameter of the clock without actually measuring it. Calculate the diameter, using the upper formula in the box.
6. In a similar way, calculate the diameter of the moon. The average distance from the earth to the moon is 385 000 km. Use the lower formula in the box. Place two strips on the window as a distance comparison.

$$\frac{\text{Diameter of coin}}{\text{Diameter of clock}} = \frac{\text{Distance from eye to coin}}{\text{Distance from eye to clock}}$$

$$\frac{\text{Diameter between tape strips}}{\text{Diameter of moon}} = \frac{\text{Distance from eye to window}}{\text{Distance from window to moon}}$$

Questions

1. What diameter did you get for the clock?
2. How can you account for variations among different measurements of the clock?

Conclusion

Ancient astronomers knew a mathematical formula necessary for calculating the distance to the moon and so were able to estimate the moon's diameter. Why can we get a more accurate measurement now?

Our moon is one of the largest natural satellites in the solar system. It has a diameter of 3476 km (2160 miles). (This is almost the same distance as from New York to Denver.) The moon is about one-fourth the size of the earth. Once the diameter of the moon is known, the volume can be calculated.

The gravitational pull of the moon is one-sixth that on the earth. This means a person weighing 120 pounds on earth (about 54 kg) would weigh 20 pounds (about 9 kg) on the moon. By knowing the gravitational pull of the moon, scientists are able to calculate the mass of the moon. Much of this information comes from the force that the moon exerts on the earth's oceans, causing tides. Since the mass and volume of the moon can be calculated, the density of the moon can also be calculated.

The moon is a silent world. On the earth, the sounds that we hear are transmitted through the atmosphere. On the moon, there is no atmosphere. Therefore, there is no sound. There is no wind and rain. There is no weathering of the moon's rocky surface. The moon is also a lifeless world. No life can exist without an atmosphere.

The force of gravity is too weak to hold any atmosphere. Water is not present on the moon. Water molecules would escape into space because of the weak gravitational pull.

Temperatures on the moon are very extreme. During the long lunar day (about 14¾ earth days), temperatures soar to

Library research

Weightlessness is often discussed in space travel. Find out how the conditions of weightlessness are simulated on the earth.

How long is a lunar day?

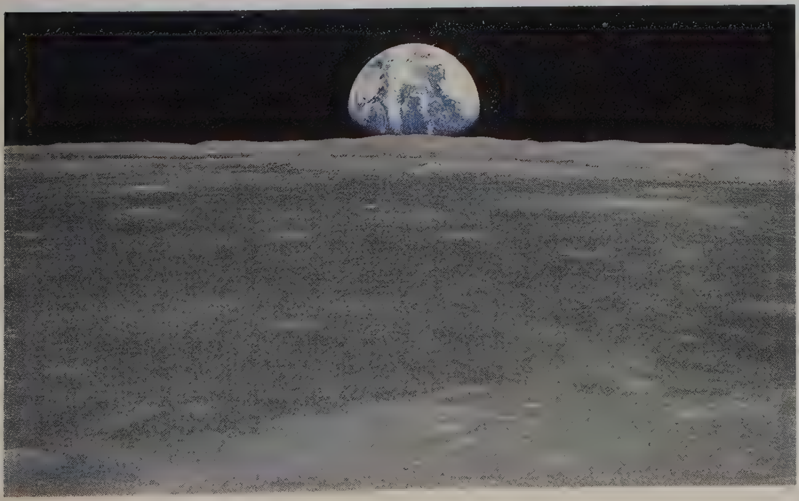


Figure 4-3. On the moon, there is no weathering of the surface, and there is no sound.

Activity Drawing an Elliptical Orbit

Materials

2 pushpins or map tacks or thumbtacks
cardboard
string
pencil
metric ruler

Purpose

To construct an ellipse.

What to Do

1. Push the two pushpins into the cardboard. Take a piece of string and make a loop.
2. Place the loop loosely around the pushpins. Pull the loop taut with a pencil point and trace out the curve that keeps the loop taut at all times. You will draw an ellipse. (If the loop is too big and goes off the cardboard, make the loop smaller.)
3. Change the distance between the tacks and redraw the ellipse.

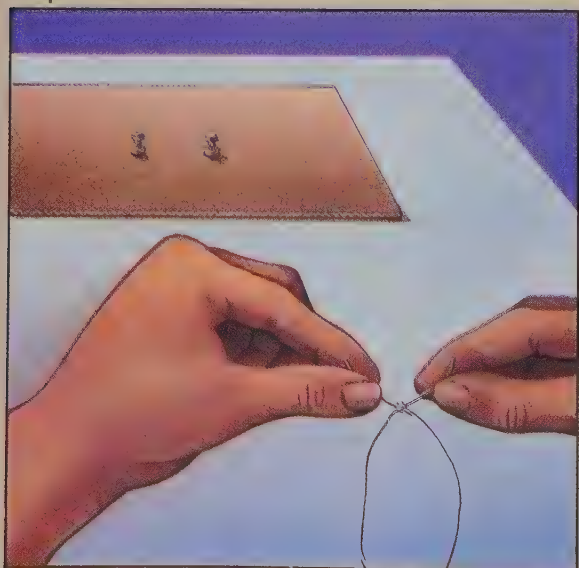
Question

What happens to the shape of the ellipse when you change the distance between the tacks?

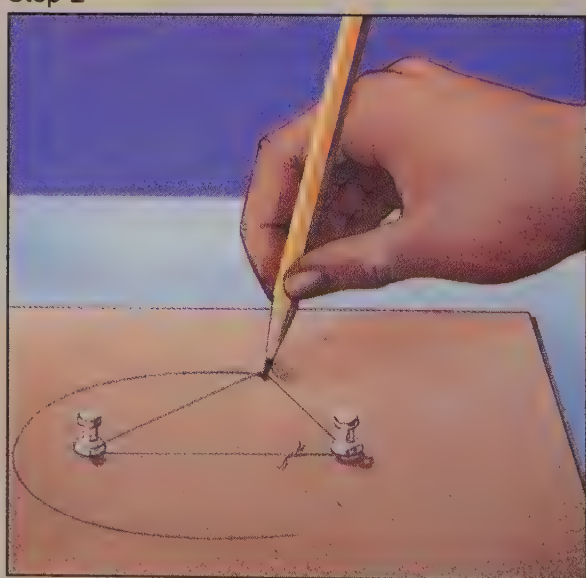
Conclusion

During part of its elliptical orbit, the moon comes between the sun and the earth and is closer to the sun than the earth is. What effect does this closeness have on the moon?

Step 1



Step 2



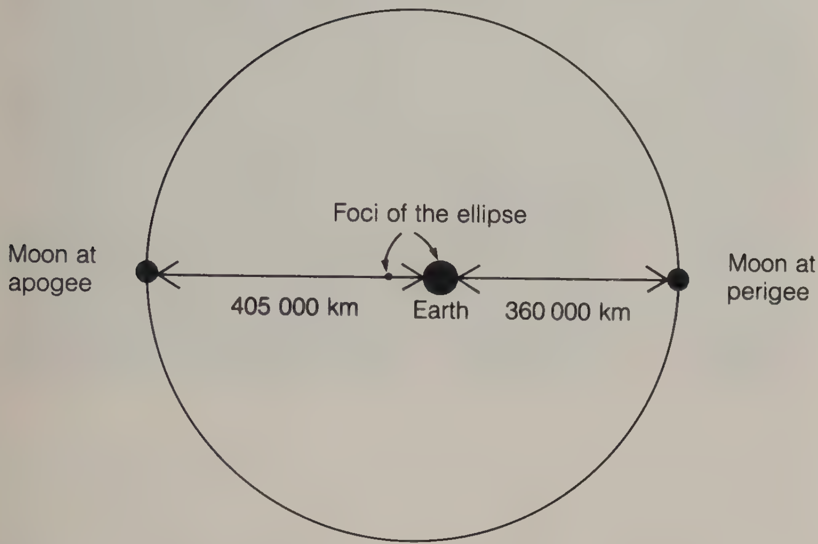


Figure 4-4. Is the moon always at the same distance from the earth?

+132°C (270°F), while the equally long lunar nights have temperatures of −120°C (−184°F). Without an atmosphere, which acts as a blanket, the heat from the lunar day is quickly re-radiated back into space.

The moon travels around the earth in a path or orbit that is shaped like an ellipse. An **ellipse** is a smooth, closed, slightly elliptical curve. It is not a perfect circle. If the moon traveled around the earth in a perfect circle, it would always be the same distance from the earth. In an elliptical orbit, there is a point where the moon comes closest to the earth. This is called **perigee** (PER′-uh-jee′). When the moon reaches perigee, it is about 360 000 km from the earth.

As the moon continues to revolve around the earth, it reaches a point opposite the perigee. This is when the moon is most distant from the earth and is called **apogee** (AP′-uh-jee′). Apogee is 405 000 km from the earth. The average distance between the moon and the earth is 385 000 km.

The moon's surface is very complex. Galileo, in his lunar observations, was responsible for naming many of the features on the moon. Galileo thought the large dark areas to be oceans, so he called them **maria** (MAHR′-ee-uh). (*Maria* is the Latin word for seas or oceans). Today these dark, relatively level areas are still called maria even though we now know that they contain no water.

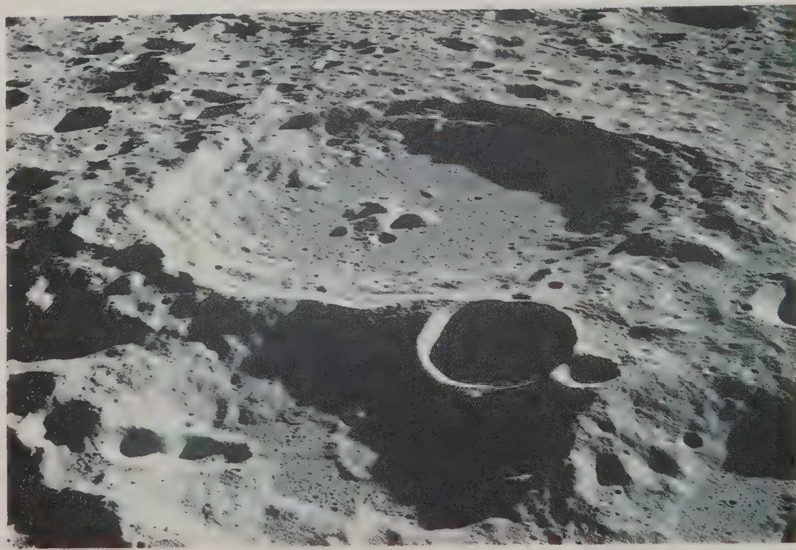


Figure 4-5. Many features of the moon's surface were named hundreds of years ago by an Italian astronomer who observed the moon's surface through a telescope. What is the name of this astronomer?

The moon has very rugged mountains many of which are as tall as the highest earth mountains. Galileo also noticed that there were craters on the lunar surface. Some of these craters had long light-colored streaks radiating from them. Galileo called these streaks rays. He also noted cracks in the moon's surface. These cracks were named rills.

Check yourself

1. Why is the moon called a satellite?
2. Compare the earth and moon with respect to an atmosphere. How does the difference affect the moon?

Phases and eclipses of the moon

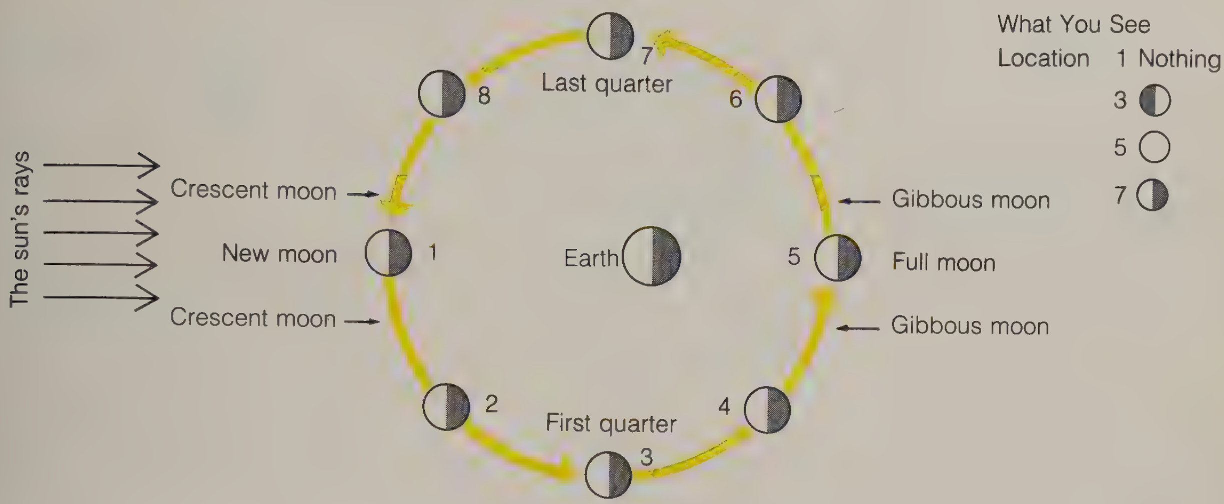
The moon reflects sunlight. Its appearance changes from a thin crescent shape to a full moon and back to a crescent. These changes are called the **phases of the moon.**

As the lighted part of the moon appears to be getting larger, we say that it is *waxing*. After reaching full moon, the lighted part begins to get smaller. This is called *waning*.

The reason we cannot always see a fully lighted moon has to do with the location of the moon in its orbit in relation to the sun and earth. Look at Figure 4-6. In Location 1, *the new moon,* you will note that you cannot see any moon because the lighted side is facing away from the earth. From the earth, the moon shows no reflected sunlight, so we cannot see it. When the moon is close to this position, only a small

Library research

What is meant by a harvest moon, a planter's moon, a hunter's moon? How were they used by people?



bit of light can be seen. This is called a *crescent moon.* In Locations 3 and 7 half the moon appears lighted. We see the entire lighted side during a *full moon.* When the moon appears almost full, it is called a *gibbous moon.*

Figure 4-6. When the moon is in Location 1, an observer on the earth cannot see any part of the moon. Why does this happen?

In Figure 4-6, note that half of the moon is always lighted by the sun, regardless of where it is in orbit. Also note that an observer on the earth can never see the entire surface of the moon because one side of the moon is always facing away from the earth.

Can the entire moon ever be seen at one time?

The moon takes 27⅓ days to make one complete rotation. It also takes 27⅓ days to make one revolution around the earth. The moon, then, revolves and rotates in the same amount of time. This is called a **sidereal month** because it is based upon the moon making one complete revolution.

A **synodic month** (si-NOD′-ik MUNTH) is based on the phases of the moon. It is the time the moon takes to go from one new moon to the next. This period of time is 29½ days. A lunar day and a lunar night are each about 14¾ (½ of 29½) earth days in length.

The difference between the sidereal month and synodic month is caused by the revolution of the earth around the sun. During the first 27⅓ days that the moon is going through its phases, the earth has been moving to a new position in its orbit. The moon needs the additional time of about 2⅙ days to come back to the new-moon position for observers on the earth.

The moon's orbit around the earth is tilted about 5° from the earth's orbit around the sun. As the moon revolves around the

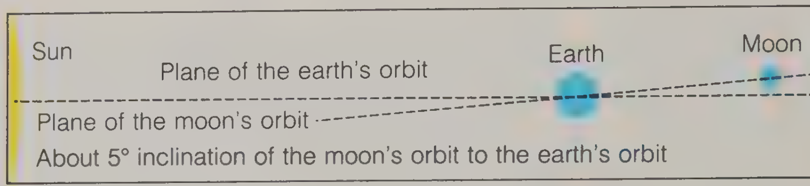


Figure 4-7. The moon's orbit around the earth is tilted about 5° from the earth's orbit around the sun.

earth, this 5° inclination keeps the moon out of the earth's shadow. If it were not for this inclination (tilt), the earth's shadow would cover the moon once every month.

When the earth's shadow does happen to fall on all or part of the moon's surface, it is called a **lunar eclipse.** A lunar eclipse can take place two to five times each year. When all of the moon is in the earth's darker shadow (called the **umbra**), a total lunar eclipse occurs. (See Location 1 in Figure 4-8.) If part of the moon goes into the umbra and part into the lighter part of the earth's shadow (called the **penumbra**), a partial lunar eclipse occurs (Location 2 in Figure 4-8). And when all of the moon is in the penumbra, a penumbral eclipse occurs.

CAUTION: *Never look directly into the sun.*

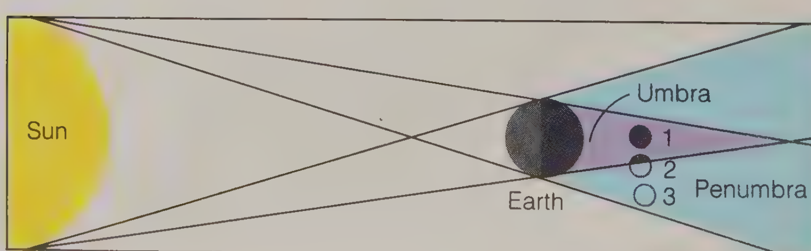
Each month, the moon passes between the sun and the earth. During this new moon phase, the moon's shadow sometimes falls on the earth, causing a **solar eclipse.** (Usually, the moon's shadow passes above or below the earth.) When the moon's umbra falls on the earth, the sun cannot be seen from that part of the earth and a total solar eclipse occurs at that place on the earth. In order for a total solar eclipse to take place, three conditions must be met at the same time.

What three conditions are necessary for a total solar eclipse?

1. The moon must be in the new moon phase.
2. The moon must be at or near perigee so that the shadow will reach the earth.
3. The sun, moon, and earth must be exactly lined up.

Solar eclipses are not rare events, but it is much less likely for a person to observe a total solar eclipse than a total lunar eclipse. This is so because the moon's umbra on the earth is

Figure 4-8. There are three types of lunar eclipses. What happens during a lunar eclipse?



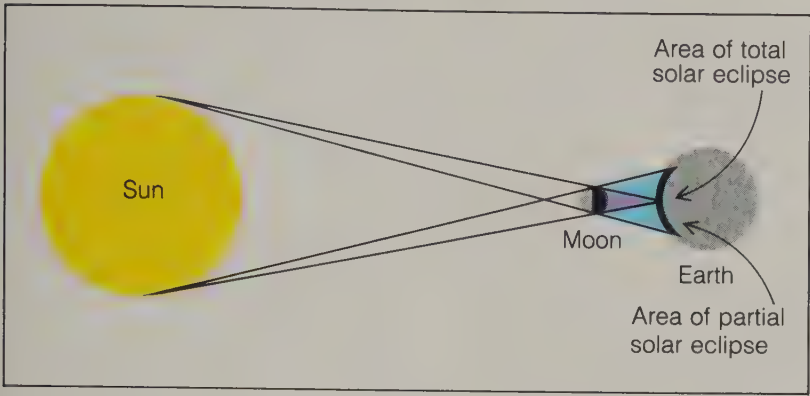


Figure 4-9. A total solar eclipse is caused by the moon's umbra on the earth. What is the moon's umbra?

never more than 260 km wide, and an observer must be within the narrow path of that shadow to witness a total solar eclipse. Also, the moon's umbra quickly sweeps across the earth's surface. At a given point on the earth, a total eclipse may last only a few seconds and never more than 7½ minutes.

To witness a partial solar eclipse, the observer need only be located within the penumbra of the moon's shadow. Since the penumbra covers a much larger area than the umbra, it is more common to witness a partial eclipse of the sun than it is to witness a total eclipse of the sun.

Library research

Record the dates for the solar and lunar eclipses that will occur during the next ten years. Examine the dates. Is there any pattern?

Check yourself

1. How does a partial lunar eclipse differ from a total lunar eclipse?
2. How does a solar eclipse differ from a lunar eclipse?

Information from the *Apollo* program

The astronauts that landed on the moon during the period of the *Apollo* space flights set up instruments, conducted scientific investigations, and probed the interior of the moon. They mapped the surface and collected samples of rock and soil. It is just now that we are beginning to understand the wealth of information obtained by the *Apollo* program.

The information brought back by the *Apollo* mission indicates that the moon is covered by a layer of lunar soil that varies from one to twenty meters in depth. Lunar soil is different from earth soils in that it did not result from the weathering and erosion of rock.

Why is lunar soil different from earth soils?

Careers Geoscience Librarian / Solar Energy Firm Owner

Geoscience librarians help scientists locate the information they need.

Geoscience Librarian Many geoscience librarians work for geological surveys and other government agencies. Others are employed by universities, petroleum and mining companies, and large public libraries.

Geoscience librarians review, purchase, and maintain collections of technical materials. These collections include information stored in computers as well as photographs, maps, books, and other printed materials.

The primary responsibility of geoscience librarians is to make the information in their collections easily available to scientists or other patrons. They help people use the library and they do some research for them.

Geoscience librarians need a background in earth science, and they must communicate information effectively. In addition, they must use various systems of storing and retrieving information, and they must do accurate and detailed work.

To train for this career, take a college preparatory course that includes a foreign language. In college, you might major in geology or a related science. Then plan to study for a year after college to earn a master's degree in library science.

The owners of solar energy firms are involved in all aspects of running a business.

Solar Energy Firm Owner
If you think you would enjoy being involved in all aspects of running a business, perhaps your goal is to start a company of your own. An interest in science and technology might lead you to consider establishing a business within the field of solar energy.

Solar energy is a small field today, but it is likely to grow rapidly in the next decade. Solar energy products that are currently available include various kinds of domestic heating systems. As we attempt to rely less on fossil fuels for our heating needs, the demand for these products should increase. Future technological developments should result in new solar energy applications as well.

There are no specific academic requirements for a business owner, but courses in business management would be helpful. Engineering, architecture, and science courses also would benefit a person who wants to design and manufacture solar energy products.

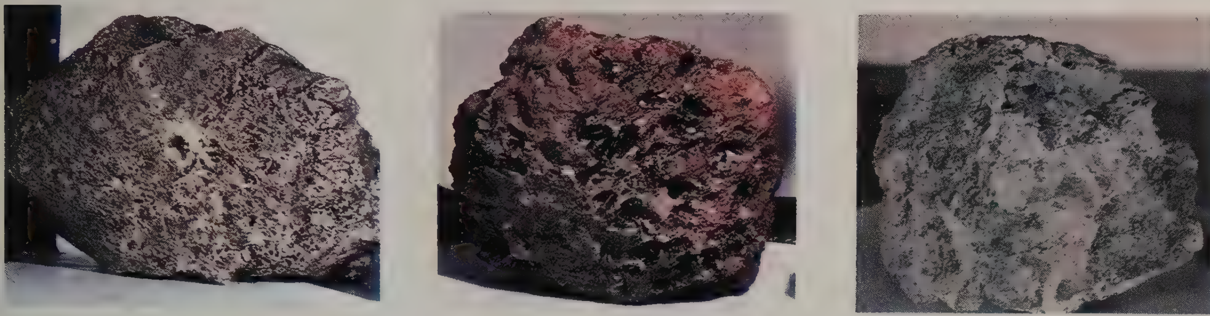


Figure 4-10. What kinds of differences can you observe among these moon rocks?

What Galileo thought to be cracks or rills actually turned out to be deep winding canyons. The craters at one time were a center of controversy. Some scientists thought the craters were of volcanic origin. Others believed them to be from meteorites striking the moon. **Meteors** are particles of stone that travel through space. When they strike the surface of an object in space they are called **meteorites.** We now know that the meteorites caused the moon's craters. When these meteorites strike the moon, they blast out large quantities of lunar soil.

From the *Apollo* mission, we learned much about the different types of moon rocks which, because the moon lacks an atmosphere and water, are better preserved than earth rocks. Moon rocks are like the igneous rocks found on the earth. Moon rocks contain the same elements and minerals as are found in most earth rocks. As with earth rocks, different moon rocks may consist of different combinations of elements and minerals.

The *Apollo* astronauts found that there was no water on the moon. They also found only tiny amounts of carbon and carbon compounds. Both carbon and water are necessary for life. Therefore, scientists have ruled out any possibility of life on the moon.

Instruments were placed on the moon to find out about the moon's interior. These instruments have indicated that there are "moonquakes" deep within the interior. These are all very weak.

The moon's interior is thought to be much like that of the earth, as shown in Figure 4-11. You can compare this diagram with that of the earth shown in Figure 1-7 on page 16.

Scientists believe that the moon and the earth are about the same age. The moon's surface was molten and cooled slowly, creating the lunar rocks. During this cooling period, the moon was bombarded by huge meteorites that created the huge ba-

Activity Simulating Lunar Craters

Materials

half-gallon milk carton
plaster of Paris
pebbles
metric ruler
newspaper

Purpose

To simulate the formation of lunar craters.

What to Do

1. Cut the milk carton about 8 cm from the bottom.
2. In the bottom of your container, make a mixture of plaster of Paris and water to a depth of about 5 cm. The mixture should have the consistency of syrup.
3. Place your container on newspapers spread on the floor. Drop three pebbles of about the same size into the mixture from three different heights above the carton.
4. Throw a pebble about the same size as the first three into the mixture—with force. The pebble should be thrown straight down.
5. Throw a pebble into the mixture at an angle.
6. Wait about 10 minutes for the plaster of Paris to harden. Repeat the procedure.
7. Examine a picture that shows moon craters. Compare these to the craters that you made in the plaster of Paris.

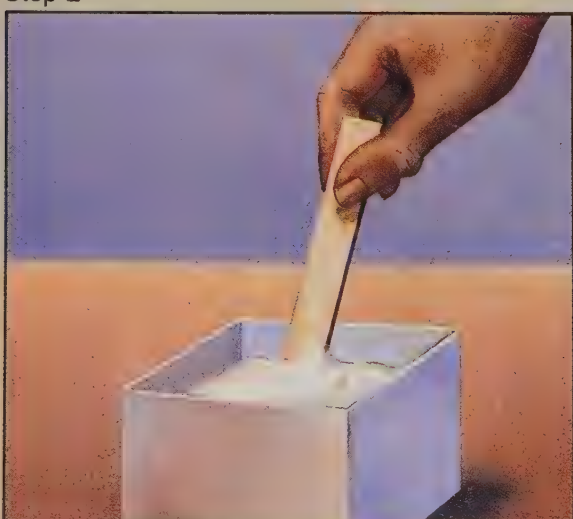
Questions

1. If the craters on the moon were formed by meteors striking a soft material like the plaster of Paris before it hardened, what would have happened to the craters?
2. If the craters on the moon were formed by meteors striking a harder material like the plaster of Paris after it had hardened, what would have happened to the craters?
3. How do your craters compare with those in the pictures of the moon?

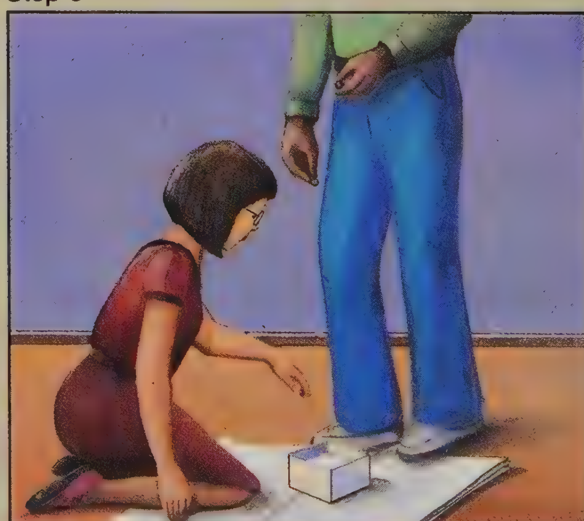
Conclusion

How do you think the craters on the moon were formed?

Step 2



Step 3



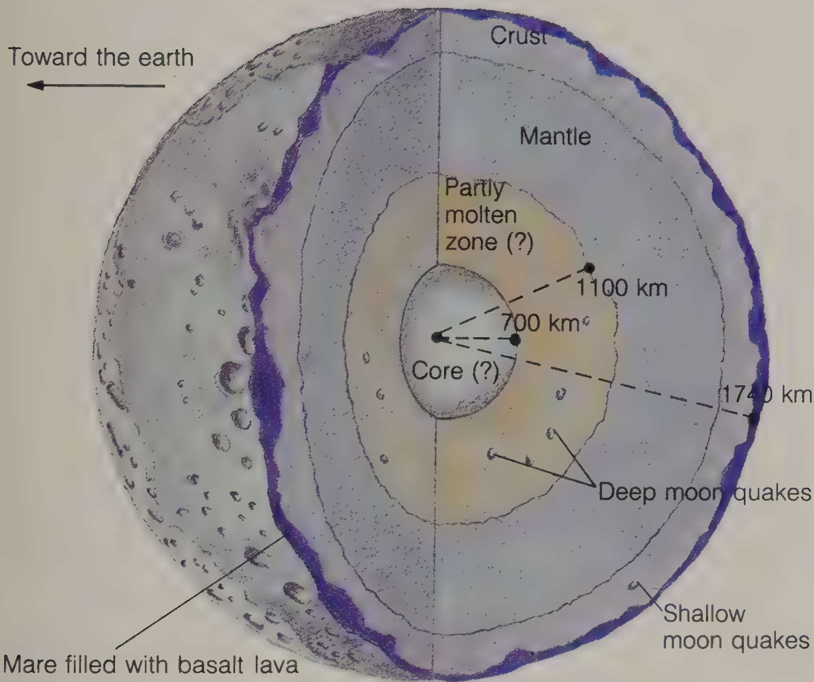


Figure 4-11. On the moon, the basins (maria) filled in with molten rock that rose to the moon's surface. On the earth, what are the basins filled with?

sins. The meteorite bombardment subsided, leaving the features of the moon as we now know it.

Heat produced by radioactive material caused molten rock. This molten rock rose to the surface and poured out onto the surface of the moon. It filled in the basins (maria) just as water fills in our ocean basins.

What source of heat caused the molten rock on the moon?

There are many questions still unanswered. For example, why is the moon egg-shaped rather than spherical? Is the moon still molten inside? Does the moon have an iron core like that of the earth's?

Answers to these questions may come from further exploration of the moon or perhaps from exploration of the planets.

Check yourself

1. How do moon rocks compare with earth rocks?
2. Why have scientists ruled out the possibility of life on the moon?

Section 1 Review Chapter 4

Check Your Vocabulary

apogee
ellipse
lunar
lunar eclipse
maria
meteorites
penumbra
perigee
phases of the moon
satellite
sidereal month
solar eclipse
synodic month
umbra

Match each term above with the numbered phrase that best describes it.

1. An object that revolves around a body larger than itself
2. A smooth, closed curve that is not a perfect circle
3. The point in the moon's elliptical orbit when the moon is closest to the earth
4. The point in the moon's elliptical orbit when the moon is farthest from the earth
5. Having to do with the moon
6. The large, dark, relatively level areas on the moon's surface
7. Recurring changes in the moon's appearance
8. A month that is based upon the moon making one complete revolution; 27⅓ earth days
9. A month that is based on the time the moon takes to go from one new moon to the next; 29½ earth days
10. When the earth's shadow falls on the moon's surface
11. The dark central part of a shadow
12. The lighter part of a shadow
13. When the moon's shadow falls on the earth's surface
14. Various sized particles of stone and/or iron that travel through space

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The point where the moon is closest to earth is called _?_.
   a) perigee c) an ellipse
   b) apogee d) a satellite
2. Maria are the dark areas on the moon. Galileo first thought these dark areas were _?_.
   a) mountains c) oceans
   b) volcanoes d) plains
3. The dark part of the earth's shadow during a lunar eclipse is known as _?_.
   a) penumbra c) earthshine
   b) moonshine d) umbra
4. A lunar day is _?_.
   a) 14¾ earth days
   b) 27⅓ earth days
   c) 1 earth day
   d) 29½ earth days
5. The moon receives its light from _?_.
   a) nuclear fusion
   b) the earth
   c) the sun
   d) coal and oil

Check Your Understanding

1. How much of the moon is lighted at any particular time? Draw a diagram that shows this?
2. Explain the difference between the sidereal month and the synodic month.
3. Why doesn't the earth's shadow cover the moon once every month?
4. Explain the difference between a solar eclipse and a lunar eclipse.
5. What do scientists believe about the moon's age and interior?

The Solar System   Section 2

Section 2 of Chapter 4 is divided into four parts:

Characteristics of the sun

A sun-centered solar system

Mercury, Venus, Earth, and Mars

The outer planets

Figure 4-12. Without the sun's energy, there could be no life on the earth. The sun's gravitational force also affects the earth. How does the sun's gravity affect the earth?

What is the solar system?

The **solar system** is the sun and all the objects that revolve around the sun. One of those objects, the earth, you have already learned much about. In this section of Chapter 4, you will learn about the sun and the planets. You will also learn about theories that led to the acceptance of the idea that the solar system is sun-centered rather than earth-centered.

Characteristics of the sun

We have all seen pictures of the sun or we have observed the rising or setting sun. We have also been warned never to look at the sun when it is shining brightly. To look at the sun when it is so bright would be harmful to our eyes. Where does the sun get all its energy? Is there an unlimited amount of oil or coal on the sun that provides the fuel for the sun?

Scientists are now quite sure that it is thermonuclear energy that keeps the sun hot and glowing. The sun is composed mostly of the elements hydrogen and helium. The temperature of the sun's surface has been estimated to be about 5500 degrees Celsius. Scientists believe that the temperatures at the center of the sun are as high as 15 million degrees Celsius. With temperatures this high, the nuclei of hydrogen have enough energy to cause them to fuse (join) with other hydrogen nuclei. This process is called **nuclear fusion.**

Library research

Sunspots occur in cycles. How do sunspots affect the earth?

When this reaction takes place, four hydrogen nuclei are fused to form one helium nucleus. In the fusing process, a small amount of matter seems to disappear. However, this "missing" matter is not really lost. It is changed into energy. It is this thermonuclear process that has kept the sun burning for at least 4½ billion years and will keep it burning at least another 4½ billion years.

To get some idea of how much energy is produced on the sun, you can think of it this way. As 0.01 grams of hydrogen is converted into helium and energy, enough energy is produced to provide your home with electricity for 2000 years.

The surface of the sun is called the **photosphere** (FŌT′-uh-sfir′), which is not really a surface but rather the highest layer of visible gases. On this "surface," there appear dark spots called **sunspots.** Scientists have been fascinated by these

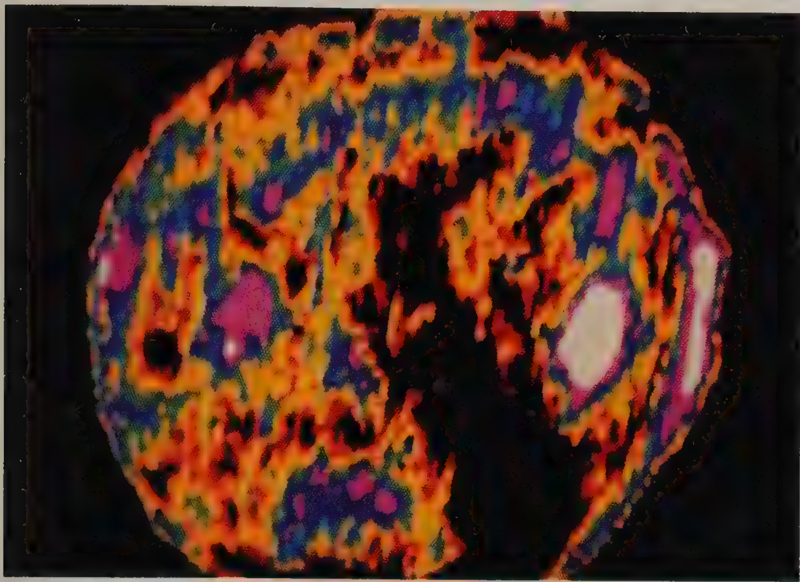


Figure 4-13. This false-color photographic representation of the sun's surface was processed from an August 20, 1973, television transmission of *Apollo* Telescope Mount from *Skylab 3*. Astronauts on board the space station could, by using monitors, control the telescope and follow changes on the sun's surface.

sunspots, which are many degrees cooler than the rest of the photosphere. Sunspots can be observed to move across the sun's surface. They have been observed to move faster in the middle of the sun than at the poles. For many years, a record has been kept about the number of sunspots. Scientists have found that the number of sunspots increases for a period of 5½-6 years, reaches a maximum, and then decreases for 5½-6 years, on the average.

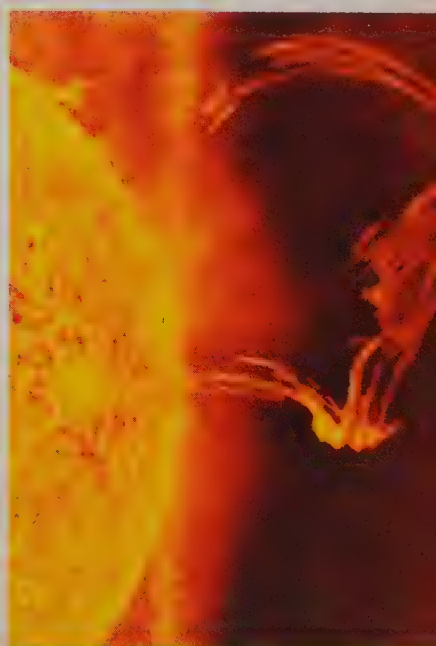
Scientists have tried to relate this periodic increase and decrease in sunspot numbers to such things as the weather, the stock market, the Ice Age, and the extinction of dinosaurs. As yet no evidence has indicated any relationships.

Solar flares are sudden bursts of energy that are given off from sunspots. These flares give off electrically charged particles that interfere with radio communications on the earth.

During eclipses or with a special telescope, scientists can observe the sun and the rest of its features. (As you recall, the sun should never be viewed directly when it is shining brightly.) The **chromosphere** (KRŌ′-muh-sfir′) is a thin layer that marks the change between the photosphere and the corona. The **corona** (kuh-RŌ′-nuh) is the outermost part of the sun's atmosphere and consists of electrically charged gases with temperatures of 2 million degrees Celsius.

Streaming out from the sun's surface are cooler gases called **solar prominences.** These prominences appear to leap out of the sun to heights of 800 000 km. They sometimes make an arc and return to the sun in another place.

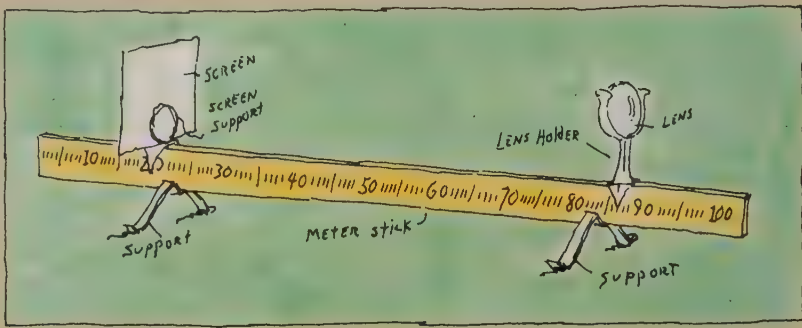
Figure 4-14. This photograph, obtained during the 1973 *Skylab 3* mission, reveals for the first time that helium erupting from the sun can stay together to altitudes of up to 500 000 miles (over 800 000 km).



Activity Calculating the Distance to the Sun

Materials

convex lens
15-cm X 15-cm white tagboard
meter stick
lens holder
paper holder
meter stick support



Purpose

To calculate the distance between the earth and the sun.

$$\frac{\text{Diameter of sun's image}}{\text{Diameter of sun}} = \frac{\text{Distance from screen to lens}}{\text{Distance to sun}}$$

What to Do

1. In Section 1, you used similar triangles to calculate the diameter of the moon. In this activity, you will use similar triangles to calculate the distance from the earth to the sun.
2. Set up the apparatus as shown in the diagram.
3. Move the lens until you get a clear, sharply defined image of the sun on your screen. *SAFETY NOTE: Never look at the sun directly. Use only shadows or some other forms of indirect observation.*
4. Measure the distance between the lens and screen. Record the information, to the nearest centimeter.
5. Measure the diameter of the sun's image on the screen. Record this information.
6. Using the diameter of the sun (1 400 000 km), calculate the distance from the earth to the sun.

Questions

1. What did you calculate the sun's distance to be?
2. Did everyone get the same answer? If not, why not?

Conclusion

How can something so far away provide the heat and light that the sun does for the earth? To find out, look back at page 186.

Figure 4-15. What occurrence on the sun causes spectacular light shows like this aurora borealis (northern lights) to appear in the earth's atmosphere?

What is solar wind?

Solar wind is streams of electrically charged particles (mostly electrons and protons) that are constantly given off from the sun. The solar wind causes spectacular bands and streamers of light to appear in the sky. These natural light shows are called **auroras** (uh-ROR′-iz). An aurora occurs when the earth's upper atmosphere in the polar regions becomes electrically charged. The northern lights, or aurora borealis, is an aurora that occurs in the Northern Hemisphere.

The sun is important to the earth because it supplies us with all our energy. The earth produces a small amount of energy of its own. This energy is from deep within the earth and is produced largely by the disintegration of certain radioactive elements such as uranium. Yet, if the sun were to go out, the earth's surface would quickly become very cold and lifeless.

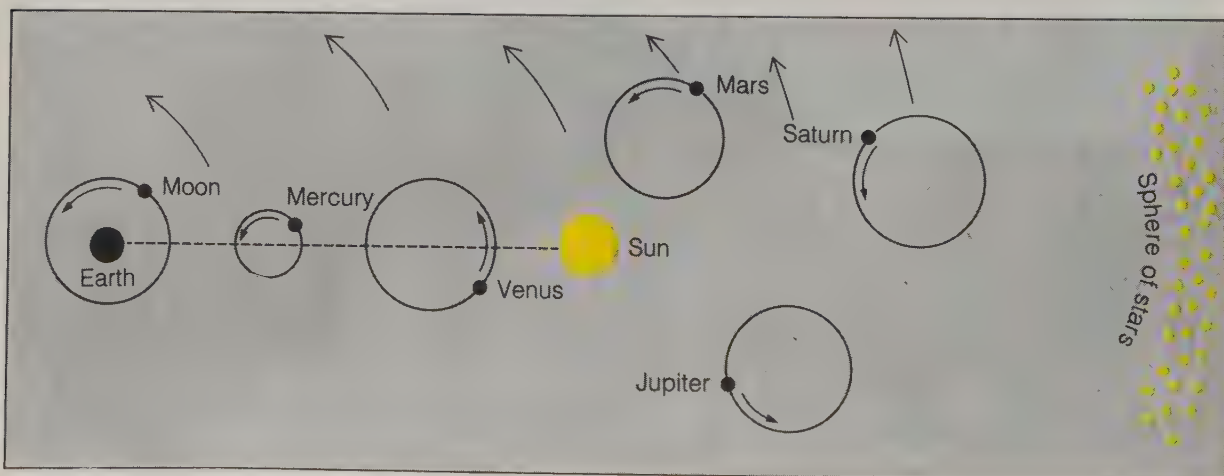
Check yourself

1. How can the sun continue to give off so much energy without "burning up"?
2. What would happen to the earth if the sun were to "go out"?

A sun-centered solar system

The sun is important as a source of energy. The sun is also important for another reason. It is the sun that holds our solar system together. From about 500 B.C. to the second century A.D., Greek, Roman, and Egyptian philosophers such as Pythagoras, Plato, Aristotle, and Ptolemy developed a plan that tried to explain the rising and setting sun, the motions of the moon, and the motions of the stars and other planets. Ptolemy (TOL'uh-mee) explained all these motions by saying that the

Figure 4-16. Was Ptolemy's system of planetary motions sun-centered or earth-centered?



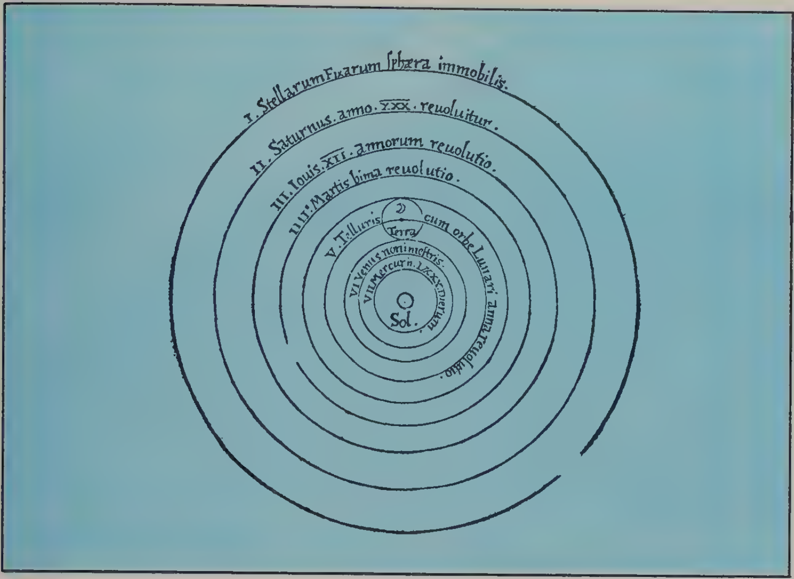


Figure 4-17. Copernicus found it easier to explain the motions of objects in the sky by assuming that the sun (*Sol*) rather than the earth (*Terra*) is at the center of the system.

earth was at or near the center of the solar system and that the earth did not move. All objects moved around the earth.

It is not hard to understand how people thought in those days. They could not see or feel the earth moving so they assumed that it was the other objects that were moving.

Why, to an observer on the earth, does the earth appear to be not moving?

About 1300 years later, a Polish astronomer named Copernicus (kō′-PER′-ni-kis) changed the ideas of the "earth-centered" solar system to a "sun-centered" solar system. Copernicus studied the motions of the planets and found it difficult to explain them, using Ptolemy's model. Certain planets seemed to reverse themselves at various times. These apparent reversals, or **retrograde motions,** could be much more easily explained if one assumed that the earth and all the other planets were revolving around the sun. Copernicus, however, was unable to prove his theory that it was actually the planets that revolved around the sun.

Tycho Brahe (TOO′-kō BRAH′-eh), a Danish astronomer, attempted to disprove the Copernican system. Brahe made countless observations of the planets. He kept very accurate and detailed notes. Brahe devised a theory that the sun revolved around the earth and that the other planets revolved around the sun.

Johannes Kepler (yō-HAHN′-is KEP′-ler), a young assistant to Brahe, inherited all of Brahe's notes and observations. After much study, he found he was unable to accept Brahe's theory. In 1609, Kepler developed two very important theories of his own. Kepler theorized that each of the planets moved about

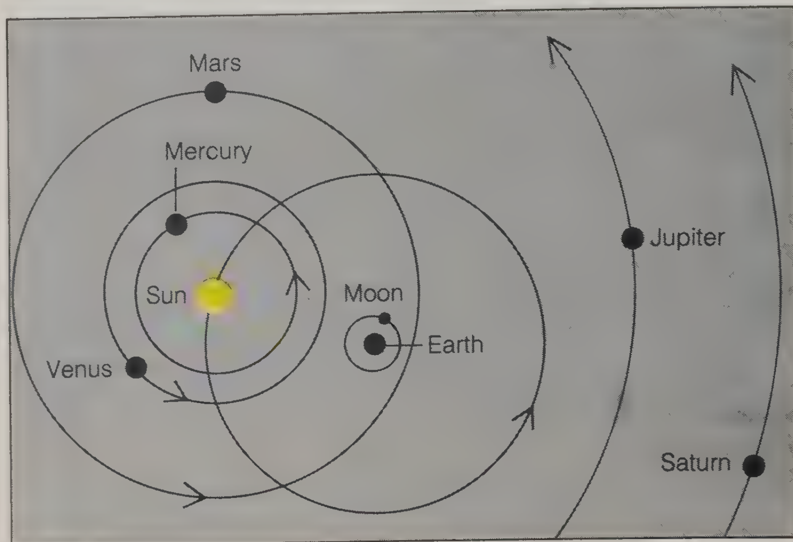


Figure 4-18. This diagram shows Brahe's theory of the movements within the solar system. How does his theory differ from those of Ptolemy and Copernicus?

Figure 4-19. With his telescope, Galileo observed that Venus had phases similar to those of the moon. What conclusion did Galileo draw from this observation?

the sun in an orbit that was slightly elliptical and that the sun was one of the foci (centerpoints).

Kepler further concluded that each of the planets revolves in such a way that as it comes closer to the sun it speeds up and as it gets farther away it slows down. Nine years later, Kepler reached a third conclusion. He found a definite proportion between the distance a planet is from the sun and the length of time it takes for the planet to revolve around the sun.

Kepler's model of the solar system was more accurate and more complete than Copernicus' model. However, both models were similar in that the earth and all the planets revolved around the sun. Yet, many people still believed that the earth was at the center.

In 1610, a strong bit of evidence was uncovered. The Italian scientist Galileo Galilei (gal-uh-LAY′-ō gal-uh-LAY′-ee) made a telescope and was using it to look at objects in the sky. He was the first to see some of the moons of Jupiter. They moved around the planet in orbits very similar to the orbits of the planets as described by Kepler. He also observed that Venus had phases similar to those of the moon. These led Galileo to conclude that Venus, the earth, and the other planets were revolving around the sun and that Copernicus was correct.

It was not until about 1665, however, when Isaac Newton introduced the **law of gravitation,** that all of Kepler's conclu-

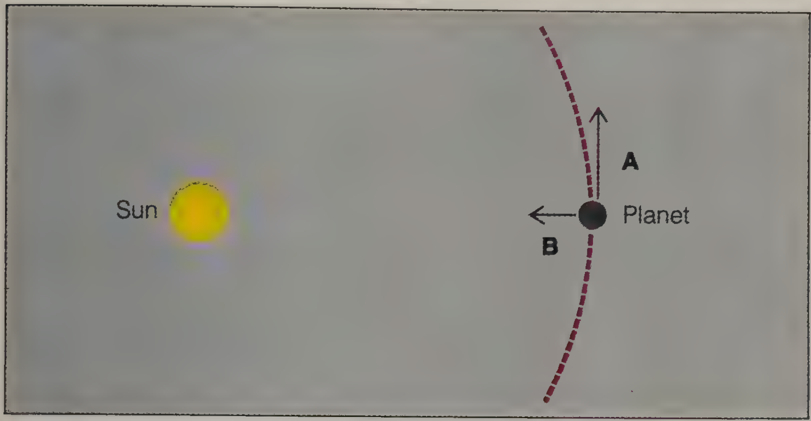


Figure 4-20. A planet is kept in motion by its motion around the sun (which tends to move out in a straight line as shown by A on the diagram) and by the gravitational interaction of the planet and the sun (B).

sions were fully accepted. Newton's law of gravitation states that there is a force of attraction between every object in the universe. This force is in proportion to the product of their masses and inversely proportional to the square of the distance between two objects.

In words, this sounds complicated. An example should help you to better understand Newton's law of gravitation. Put a textbook on the desk. Now put another object such as a pencil 1 m away. What Newton said means that there is a measurable force between the book and the pencil. This force can be found by multiplying the mass of the book times the mass of the pencil and then dividing by the square of the distance between the pencil and the book.

Why don't the pencil and the book come together? The gravitational force between the desk and the objects is greater than the force of attraction between the pencil and the book. Therefore they remain in place. The force of friction is also a factor in keeping the book and the pencil from coming together.

What does Newton's law of inertia state about a body in motion?

Newton was also responsible for discovering some other important laws. The **law of inertia** (in-ER′-shuh) is one. This law states that a body in motion will remain in motion with a constant speed in a straight line unless acted upon by another force. A body at rest will remain at rest unless acted upon by an outside force. In the example mentioned previously, the book and the pencil are at rest.

Surrounding the sun are nine planets and their satellites. It is their motion around the sun and their gravitational interac-

tion with the sun that keeps these objects in orbit. If their gravitational interaction were to suddenly stop, the planets would go flying through space in a straight line. If the sun's gravity were to increase, the planets would need to speed up in order to keep from being pulled into the sun.

How do scientists think that our solar system was formed?

Scientists now think that our solar system was formed by a huge whirling cloud of gas and dust. Gradually this cloud collapsed inward. The innermost part became very massive and hot, forming our sun. The planets and their satellites formed from the outer dust. It is estimated that this took place 4.6 billion years ago. Moon rocks have been dated at 4.3 billion years and earth rocks at 4.0 billion years.

It is important to remember that no one theory for the origin of the solar system is accepted. Most astronomers agree, however, that the entire solar system was formed at the same time.

Check yourself

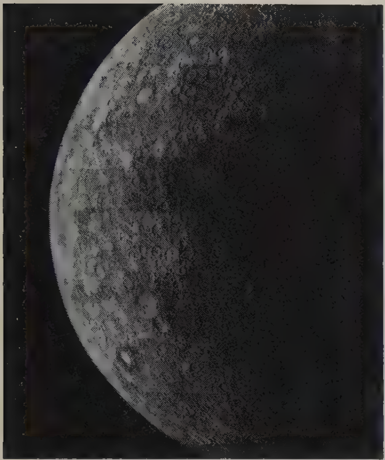
1. What would happen if the sun's force of gravity were to weaken? What would happen if it were to become stronger?
2. How do scientists think that our solar system was formed? When do they think this happened?

Mercury, Venus, Earth, and Mars

Our solar system can be divided into the first four planets, sometimes called the "inner" planets or the terrestrial (earth-like) planets, and the remaining planets, referred to as the "outer" planets. Table 4-1 gives data for all the planets.

Mercury. The planet Mercury is the closest planet to the sun. In many ways, Mercury is like our moon. It has many craters and no atmosphere. Like the moon, Mercury rotates very slowly. The side facing the sun is very hot and may even have pools of molten metal. There is also evidence of lava flows.

Venus. Venus is the second planet from the sun. It is the third brightest object in the sky after the sun and the moon. Sometimes Venus can be seen in the early evening. At other times,



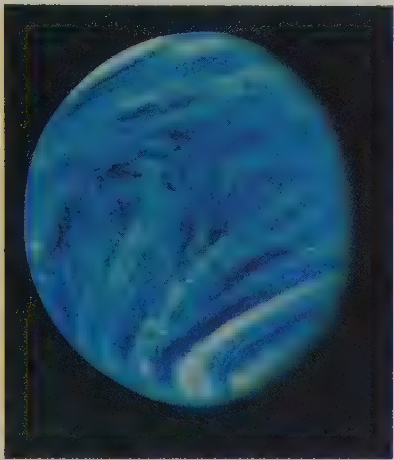


Figure 4-21 (*on the left*). The planet Mercury is the closest planet to the sun.

Figure 4-22 (*on the right*). Venus, the second planet from the sun, is surrounded by pale yellow clouds.

Venus can be seen in the early morning. For this reason, Venus is often called the morning star or evening star.

In mass, size, and density, Venus is much like the earth. But Venus is much hotter, it has a denser atmosphere (mostly carbon dioxide), and it rotates more slowly than the earth.

Venus is surrounded by pale yellow clouds that prevent us from observing the planet with telescopes. It is thought that these clouds contain droplets of sulfuric acid.

Table 4-1. Which planet takes more than 248 years to revolve around the sun?

Planet	Mean Distance from the Sun		Diameter		Period of One Revolution Around the Sun (in earth days and years)	Period of One Rotation on Its Axis (days = earth days)	Number of Satellites
	in millions of km	in millions of miles	in km	in miles			
Mercury	57.94	36	4988.97	3100	87.97 days	58.66 days	0
Venus	108.26	67.27	12 391.95	7700	224.7 days	243.2 days	0
Earth	149.67	93	12 757.27	7927	365.256 days	23.93 hours	1
Mars	228.06	141.71	6759.25	4200	1.881 years	24.62 hours	2
Jupiter	778.73	483.88	142 748.81	88 700	11.862 years	9.83 hours	16
Saturn	1427.71	887.14	120 861.73	75 100	29.458 years	16.65 hours	21-23
Uranus	2871.04	1783.98	51 499.01	32 000	84.013 years	12.8 hours	15
Neptune	4498.86	2795.46	44 578.83	27 700	164.794 years	15.8 hours	2
Pluto	5914.77	3675.27	2414.02	1500	248.430 years	6.33 days	1

Why are surface temperatures on Venus so high?

Venus is a very hot planet. Solar energy reaching the surface of Venus is prevented from escaping by the dense atmosphere and clouds. This greenhouse effect, together with the closer distance to the sun, keeps the surface temperatures very high (over 800°F, which is hot enough to melt lead).

Spacecraft have landed on Venus and the information they provided was vastly different from what was first thought about the surface of Venus. Venus has deep canyons and many basins and volcanoes. The rocks found on Venus are similar to the basalt found on the earth and the moon. The mountains and surface features of Venus are not as high or as rugged as those found on the moon or the earth. There is evidence of erosion of some type because many of the rocky features are rounded and smooth.

Earth. The planet Earth is the third planet from the sun and the fifth largest in size. About four-fifths of the surface of Earth is covered by water. The one-fifth that makes up the land areas is of varied composition and topography. Earth is surrounded by an atmosphere of gases that process energy from the sun.

Figure 4-23. How do water and the atmosphere affect the environment on the planet Earth?

Earth travels around the sun once every 365 days and 6 hours (approximately) at a rate of 67 000 mi (107 826 km) per hour. Because Earth is tilted on its axis, differing amounts of the sun's energy are received around the surface of Earth. As a result, seasons occur around the planet.

Earth's atmosphere and water provide an environment capable of supporting life. Earth is the only planet on which life is known to exist.

Mars. The planet Mars is the fourth or last of the inner planets. Ancient astronomers knew about Mars from observation. They observed Mars move across the sky from west to east against the "fixed" stars and constellations. The other planets were also observed to move in a similar pattern. The ancient astronomers thought these were special stars and called them planets. (The word *planet* is from a Greek word that means to wander around.)

The surface of Mars is unique in that it is divided into three sections. The Southern Hemisphere is a heavily cratered region. There is a second region that consists of a volcanic plateau 4 to 10 km in height and extending over an area of about 4000 km.

Library research

If you were to observe Venus at various times of the year, you would find that it varies in brightness. Find out why.

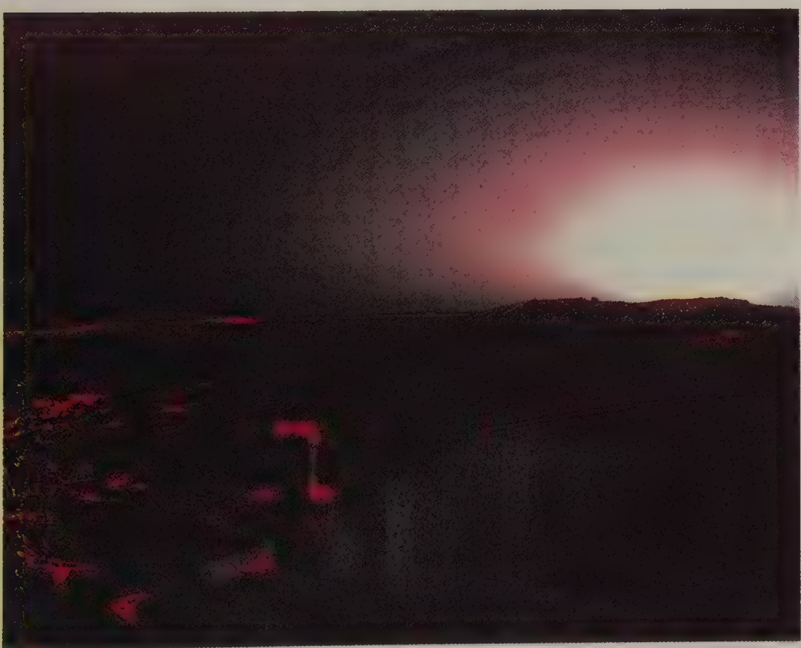


Figure 4-24. In this illustration, the sun has already set on Mars. The colored rings and the white spot show where the sun has set. They were produced in the computer processing of the camera's pictures. A human eye would have seen a black night grading uniformly to a reddish glow where the sun had set.

Figure 4-25. On February 17, 1977, *Viking 1* digs a trench up to 30 cm deep on the surface of Mars to obtain samples of Martian soil.

The third section is a low-level plains region found primarily in the Northern Hemisphere. The plains section is composed of a mixture of volcanic debris and windblown sediments.

Astronomers over the years have observed tremendous dust storms on Mars. These dust storms seem to occur when Mars is at perihelion (nearest, in its orbit, to the sun).

Mars has a thick crust, probably due to its small size and to rapid cooling.

It was often thought that if life existed on any of the other planets, it would be found on Mars. One of the reasons for the possible existence of life on Mars is that Mars has polar icecaps similar to those on Earth. These icecaps get larger and smaller, indicating that Mars has seasons. The changing seasons on Mars can be explained by the inclination of its axis at 25° and by its very elliptical orbit. (At its closest point, Mars is 206 million miles from the sun. At its farthest point, Mars is 249 million miles from the sun.)

Surface temperatures on Mars vary greatly due to the dust storms, seasons, and its location in orbit. The observation of

what appear to be dried riverbeds led to the idea that perhaps at one time there was enough liquid water to support life. Since the earth has undergone an Ice Age, perhaps Mars is also undergoing a similar climatic change. The two *Viking* spacecraft which landed on Mars in 1976 searched for signs of life, but the results of the experiments were inconclusive. Further exploration will be necessary to prove whether or not Mars has ever supported life.

Mars has two satellites that revolve very close to their planet. Astronomers believe that these tiny satellites, Phobus and Deimos, were once asteroids and were captured by the gravitational pull of Mars.

Between the orbit of Mars and the orbit of Jupiter is a region that contains many small rocky objects called **asteroids.** These asteroids, which are too small to be planets, revolve around the sun just as planets do. Astronomers have discovered 2000 of these objects.

One of the larger asteroids is called Ceres. Ceres is approximately 730 km in diameter.

It has been calculated that there should be another planet in the area where these asteroids are located. It is theorized that these asteroids are actually fragments of a planet that exploded or that was never completely formed. For this reason, asteroids are also called planetoids or minor planets.

Library research

What methods are used to change the direction of a space capsule while in flight? How are yaw, pitch, and roll accomplished? Use diagrams to show how they are done.

Why are asteroids also called planetoids or minor planets?

Check yourself

1. In what two ways is Mercury like Earth's moon?
2. In what three ways are Venus and Earth similar? In what three ways do they differ?
3. What is one indication that there are seasons on Mars?

The outer planets

The purpose of the *Voyager* mission was to explore the planets Jupiter, Saturn, and Uranus.

Activity Constructing Scale Models of the Solar System

Materials

adding-machine tape, 1 m long
meter stick
pencil
data from Table 4-1 on page 195
drawing compass

Purpose

To draw a model of the solar system.

What to Do

1. The distance from the earth to the sun (93 million miles or 149.67 million kilometers) is often used as a standard of comparison for measuring distances within the solar system. This distance is often referred to as one astronomical unit (1 A.U.).
2. Rounding off the distances on Table 4-1 to the nearest million miles, convert the distance from the sun to each planet to an astronomical unit. (Since, for example, the distance from the earth to the sun is 1 A.U., then the distance from Venus to the sun is 67 ÷ 93 or 0.7 A.U.)
3. On the adding-machine tape, plot the relative distances of the planets from the sun. On one end of the tape, make a dot and label it as the sun. Using 1-cm distance for each astronomical unit, place each planet at the appropriate scale distance from the sun. (Earth will be 1 cm from the sun.) Label each planet.
4. Using a compass, a ruler, and the data on Table 4-1, construct scale drawings that show the relative sizes of the planets. (Let the diameter of Pluto be a 1-mm dot and stand for 1 unit of measure.) Begin your drawings at the 50-cm mark on the adding-machine tape.

Questions

1. In your scale model of solar system distances, was there a place between any two planets where you feel another planet could be placed? If so, where?
2. In your scale model of solar system sizes, how could you divide the planets into two groups according to size?

Conclusion

Why is there such a big space between Mars and Jupiter? Review page 199 to see what scientists believe.

Step 3

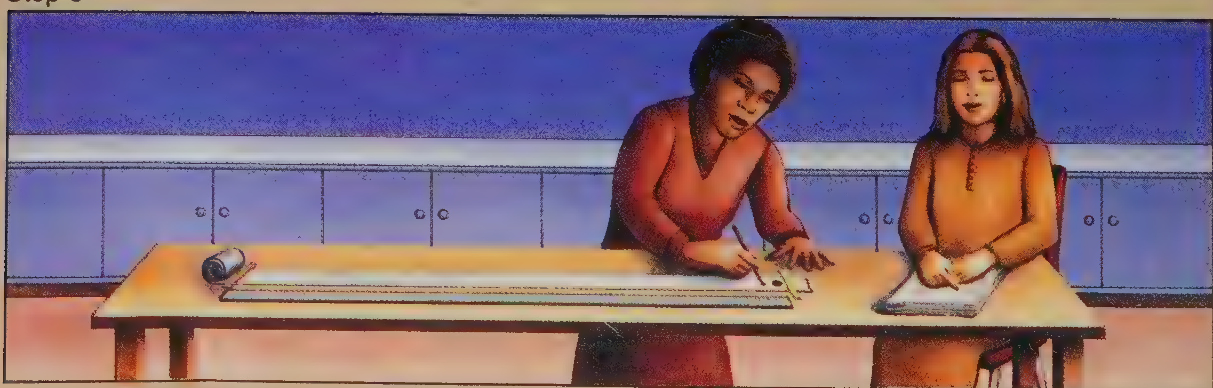


Figure 4-26. In early March, 1979, Jupiter (with the colored bands) and its four planet-size moons were photographed and assembled into this composite picture. The planet and its satellites are not to scale, but they are in their relative positions.

Jupiter. In 1979, *Voyagers 1* and *2* sent back to the earth extensive photographs of Jupiter and its moons. In 1610, Galileo saw the four largest of Jupiter's moons through his telescope. It is now known that Jupiter has sixteen satellites.

Jupiter is the largest of the nine planets. It is about eleven times larger than the earth and it rotates much faster than the earth. Jupiter makes one complete rotation in about ten hours.

For many years, the Great Red Spot on Jupiter had been a mystery. The *Voyager* mission has revealed that it is actually a tremendous atmospheric storm. Scientists estimate wind speeds of 120 meters per second (268 miles per hour).

What are the names of Jupiter's largest moons?

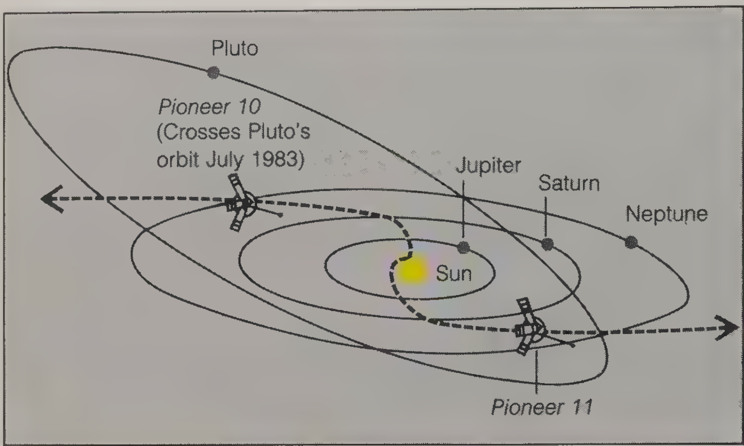
Jupiter's four large satellites are named Io, Europa, Ganymede, and Callisto. Io and Europa are closer to Jupiter and are much younger than Ganymede and Callisto.

Ganymede, the largest of Jupiter's satellites, is about one and one half times the size of our moon. Because it is only half as dense, astronomers believe it is about 50% rock and 50% water and ice. The surface of Ganymede indicates mountain building, faulting, volcanism, and meteoric impact craters.

Callisto is about the same size as Ganymede, but it is less dense. Of the four larger satellites, Callisto is the most heavily

Our Science Heritage

A Model of the Solar System



In their attempt to understand complicated processes, scientists create models which incorporate all existing data and theories as to how that data might be explained. The models can also be changed to incorporate new data and new theories.

The present model of the solar system includes nine planets that orbit the sun. In addition, satellite moons orbit the planets. When seen in motion, a working model of the solar system may seem very logical and easy to accept as a fact. But the present model represents centuries of disputes, investigations, theories, and revisions of the working model.

There is much information available about the revisions of the solar system model that have occurred over the years. One major revision had to do with placing the sun rather than the earth at the center of the system. Other revisions were brought about by the discovery of Uranus (1781), Neptune (1846), and Pluto (1930).

The existence of Neptune was predicted because of variations in the orbit of Uranus. It was felt that such variations could best be explained by the gravitational pull of another planet farther away from the sun than Uranus. A telescope directed to the location discovered the planet Neptune, just as predicted.

In 1978, the discovery of a moon circling Pluto enabled scientists to measure that planet's mass, which appears to be far less than expected and not enough to explain the orbital variations of Neptune and Uranus. Until some other massive source of gravity is found, our model of the solar system cannot be considered. Perhaps data provided from the outward-traveling spacecraft *Pioneer 10* and *11* will lead to a more complete model.

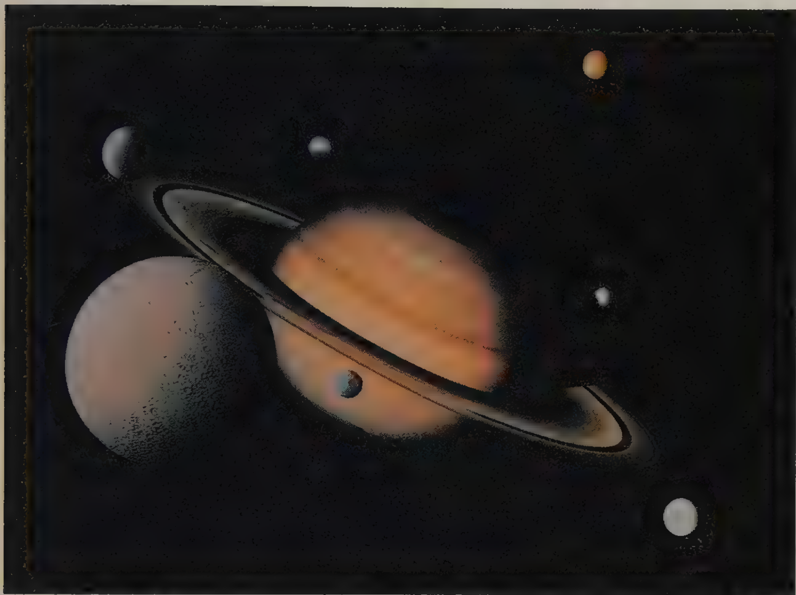


Figure 4-27. This composite picture, a montage, combines photographs taken by *Voyagers 1* and *2* of Saturn and its major satellites.

cratered. Scientists therefore believe it to be the oldest of the satellites. Its low density indicates more ice and water are present than on Ganymede.

Jupiter has one other satellite that has attracted much attention. It is called Amalthea. Amalthea is closest to Jupiter, very tiny, and elongated rather than round.

Voyager 1 also discovered that a thin, flat ring of particles surrounds the giant planet of Jupiter.

Saturn. As *Voyagers 1* and *2* left Jupiter behind and moved on toward Saturn, they began sending photographs of the ringed planet. The first startling discovery was that the period of rotation of Saturn was twenty-four minutes longer than had first been calculated from Earth.

The surface of Saturn is not as spectacular as that of Jupiter. Because it is much colder, chemical reactions are less apt to take place.

Voyager 2 sent back photographs showing bands of brown, gray, and tan in the atmosphere. These bands represent storm systems. Saturn was also found to have a large oval spot similar to the Great Red Spot on Jupiter. Most of Saturn's atmosphere

Which planet is referred to as the ringed planet?

Library research

When was Halley's Comet last seen? When will it next appear? What new information was learned at the time of its last appearance? What new instruments were used in making those observations?

is composed of hydrogen and helium. Wind velocities are 400 to 500 meters per second.

Saturn has intrigued scientists for many years because of its rings. *Voyagers 1* and *2* revealed that the five major rings are actually made up of hundreds of ringlets. Scientists are reasonably sure that these rings and ringlets are composed of ice.

Many new satellites have been recently discovered in the Saturn system. (*Voyager* photographs have confirmed their existence.) Most of them are small and irregular in shape. These satellites are composed of water, ice, and rock. One satellite that orbits Saturn, called Titan, is the largest satellite in our solar system. The other satellites that orbit Saturn are unusual in that they are small but have very large and deep craters. As more and more information is gathered, the number of actual satellites that orbit Saturn will probably be revised upward.

Uranus. On a clear night, Uranus (YŎŎR′-uh-nis or yo͞o-RAY′-nis) can be seen with a pair of binoculars. Uranus has fifteen satellites, all of which are smaller than the earth's moon. These are not visible, even with telescopes.

The atmosphere of Uranus is similar to that of Saturn and Jupiter. It is composed mostly of hydrogen and helium.

The axis of Uranus is very different from the axis of any other planet. It is almost parallel to the plane of its orbit.

It has been discovered that Uranus has rings similar to those of Saturn. Other recent discoveries indicate that Uranus may be larger than first estimated and that Uranus is less dense than water.

Neptune. The planet Neptune lies beyond Uranus and has two satellites. One of Neptune's satellites is called Triton. Actual measurements of this satellite have not been made. It may turn out that this satellite will be the largest of our solar system.

Pluto. The most distant planet from the sun is Pluto. It was once thought that Pluto was a satellite of Neptune that somehow escaped from orbit. This theory has been proposed because Pluto is more like a moon than a planet. The orbit of Pluto is very elliptical. As a result, Pluto occasionally passes between the sun and Neptune. This leads scientists to theorize that perhaps Pluto is a comet.

Figure 4-28. A comet is thought to be a mass of frozen gases mixed with rocky material. What causes the tail of a comet to glow?

A **comet** is thought to be a mass of frozen gases mixed with rocky material. As a comet approaches the sun, some of the frozen gases vaporize and form a long tail that appears to glow. The "glow" is actually the reflection of sunlight.

Comets have orbits that are very long and narrow ellipses. Comets, therefore, move in and out of our solar system. In most cases, comets take several thousand years before they return to our solar system. A few comets, such as Halley's Comet, return in shorter periods of time.

Check yourself

1. What effect did the *Voyager* mission have on Galileo's estimate of the number of Jupiter's satellites?
2. What is unusual about the axis of Uranus?
3. Why do scientists theorize that Pluto may be a comet?

Section 2 Review Chapter 4

Check Your Vocabulary

asteroids	photosphere
aurora	retrograde motions
chromosphere	solar flares
comet	solar prominences
corona	solar system
law of gravitation	solar wind
law of inertia	sunspots
nuclear fusion	

Match each term above with the numbered phrase that best describes it.

1. The sun and all the objects that revolve around the sun
2. The joining together of lightweight nuclei into a nucleus with greater mass
3. The surface of the sun
4. Dark spots on the photosphere
5. Sudden bursts of energy from sunspots
6. A thin layer that marks the change between the photosphere and the corona
7. The outermost part of the sun's atmosphere
8. Cooler gases that appear to leap out of the sun to great heights
9. Streams of electrically charged particles constantly given off from the sun
10. A natural light show caused by the effects of solar wind in the earth's atmosphere
11. Apparent reversals in the motions of certain planets
12. A scientific law, introduced by Isaac Newton, that states that there is a force of attraction between every object in the universe
13. A scientific law, introduced by Isaac Newton, that states that a body at rest will remain at rest and a body in motion will keep moving in the same direction unless acted upon by some outside force
14. Fragments of rocky objects that revolve around the sun and that are smaller than planets
15. An object with a very oblong orbit that forms a long glowing tail as it approaches the sun

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. __?__ is the scientist who changed the idea of the "earth-centered" solar system to a "sun-centered" solar system.
   a) Plato c) Aristotle
   b) Ptolemy d) Copernicus
2. The scientist who discovered the laws of gravitation and inertia was __?__.
   a) Kepler c) Ptolemy
   b) Newton d) Copernicus
3. Two planets with polar icecaps are Earth and __?__.
   a) Venus c) Mars
   b) Mercury d) Jupiter

Check Your Understanding

1. Why is the sun important to the earth and all the planets?
2. What happens in the nuclear fusion process? What happens to the matter that is "lost"?
3. Describe three important theories or conclusions that Kepler formed with regard to planetary motions.
4. Using Newton's Law of Inertia, explain why a person standing on a bus falls forward when the bus stops.
5. Of the planets other than the earth, which is your favorite? What characteristics of the planet make you feel as you do?

The Stars Section 3

Section 3 of Chapter 4 is divided into four parts:

Characteristics of stars

Different kinds of stars

Recent discoveries about the universe

Space exploration in our age

Figure 4-29. Each star is actually a sun. Why does the sun appear much larger and brighter than the other stars?

Each of the stars that you see in the nighttime sky is a sun. The reason that the stars appear to be so small and dim while the sun appears so large and bright is that the sun is much closer to us.

Characteristics of stars

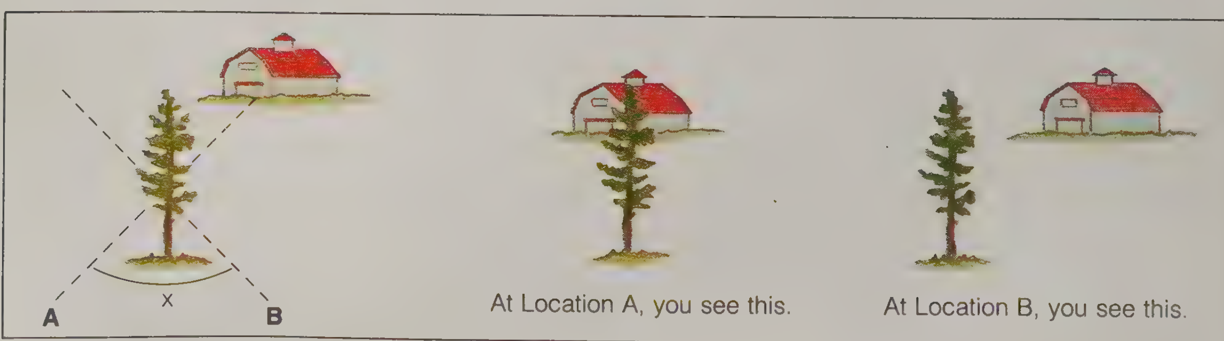
How far away is a star? Astronomers can learn a great deal if they know the distance to stars. There are two basic methods that are used to measure stellar distances. (*Stella* is the Latin word for star.) One method is based on angles and the other is based on the brightness of a star.

Angle X in Figure 4-30 shows the kind of angle that is used in measuring distances to nearby stars. Imagine yourself in the diagram. When you look at the tree from Location A, the tree and the building are lined up. When you move to Location B and look at the tree, the tree will appear to the left of the building. The shift in the relative positions of the tree and the building is caused by the difference in the direction from which you are viewing the tree. The difference in the direction of the line of sight to an object from two different places is called **parallax** (PAR′-uh-laks′). And the resulting angle (angle X in the diagram) is called the **parallax angle.**

You can use the parallax angle and the distance between A and B to calculate the distance from the observer to the tree. You can also use the parallax angle and the distance between two observation points to calculate the distance to a star.

To determine the distance of nearby stars, astronomers observe a star two times, six months apart. Six months after the

Figure 4-30. As you move from Location A to Location B, what will happen to the relative positions of the tree and the building?



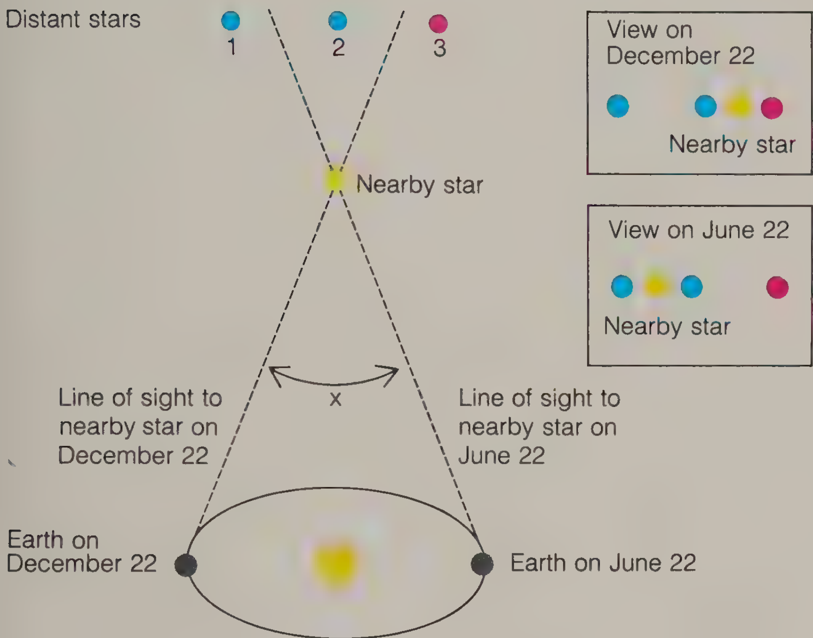


Figure 4-31. When obtaining the parallax of a "nearby" star, why are the astronomer's observations made six months apart?

first observation, when the earth has traveled one half of its orbit around the sun to a point just opposite its original position, the amount that the star appears to shift against the background of more distant stars helps the astronomer calculate its distance from the earth. (See Figure 4-31.) Because stars are so far away, the distance to a star is measured in light years. A **light year** is the distance that light travels in one year, at the speed of 300 000 km (186 000 miles) per second.

The parallax method of measuring stellar distances is useful only for the thousand or so stars that are within about sixty-five light years of the earth. As stars become more distant than that, their parallax becomes increasingly more difficult to detect. To see how distance affects parallax, hold up your thumb about a foot in front of you. By winking, look at your thumb through only your left eye and then through only your right eye. Parallax will cause a change in the position of your thumb against the background. Now have a friend across the room hold up his or her thumb. When you wink and sight your friend's thumb through one eye and then through the other, you probably will not notice any change in position. The parallax will be too small.

Library research

Stellar distances are frequently expressed in parsecs. What is a parsec?

How can you use your thumb to observe parallax displacement?

Activity Observing Parallax Displacement

Materials

clay
tabletop or board 120 cm long
2 toothpicks

Purpose

To see how parallax displacement works.

What to Do

1. Place each toothpick upright in a lump of clay. Put one toothpick at the far end of the table. Put the other toothpick about 30 cm from the near end.
2. Standing at the near end (the end without the toothpick), crouch down until you are eye-level with the tabletop and the toothpicks. Line the two toothpicks up so that they appear even with your nose.
3. With both eyes open, focus on the near toothpick (the one 30 cm from the near end). Close first one eye and then the other.
4. Focus on the far toothpick and follow the same procedure.

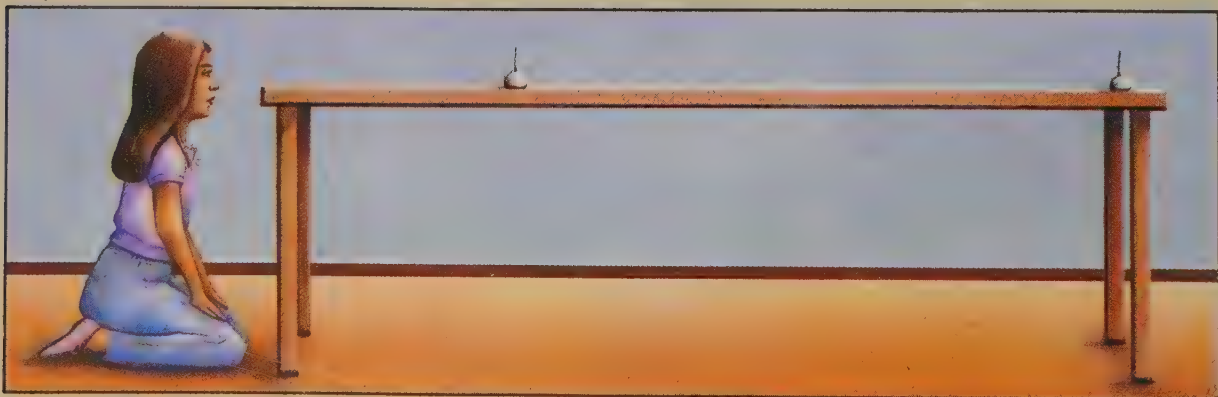
Questions

1. What happens to the far toothpick when you focus on the near one?
2. What happens when you focus on the far one?

Conclusion

Compare your observation of parallax displacement in this activity with the use of parallax displacement to measure the distance to stars.

Step 2



For any star too far away for the parallax method, its distance is calculated by analyzing a photograph of the spectrum of light received from that star. In this method, the star's brightness is used to determine its distance.

In the second century B.C., Hipparchus (hi-PAR′-kis) devised a way of grouping stars into classes according to their **apparent brightness** (their brightness as observed from the earth). Each of these brightness classifications is known as **magnitude** (MAG′-nuh-tood′). Hipparchus classified the brightest stars as first-magnitude stars and the dimmest stars as sixth-magnitude stars. Each of the other visible stars was grouped into one of the in-between magnitudes (second, third, fourth, or fifth). Modern photographic processes enable more precise observations of a star's apparent brightness, but Hipparchus' system of magnitudes is still used. Figure 4-32 shows the kind of scale astronomers use to estimate the magnitude of stars in photographs.

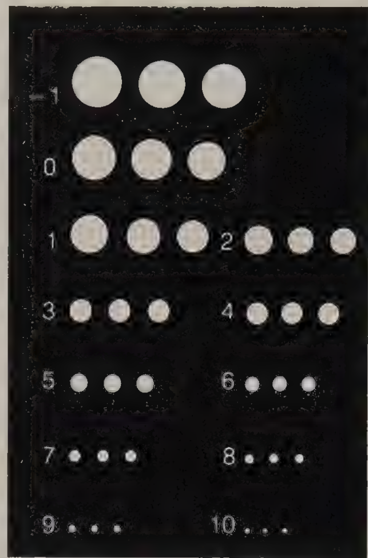


Figure 4-32. Astronomers use this kind of scale to estimate the magnitude of stars that have been photographed.

Classifying stars by apparent brightness is based on how bright the star appears to an observer on the earth. But this does not represent a star's **true brightness**—the amount of light it is giving off, or its luminosity (loo′-muh-NOS′-uh-tee)—because stars are located at very different distances from the earth. From experience, you know that a light appears to get dimmer as the distance between you and it increases. Astronomers have devised a scale that tells how bright stars really are if they were all compared from the same distance (32.6 light years). This brightness is called **absolute magnitude.** Our sun, if placed at the same distance as any other star, would appear very dim.

How bright would our sun appear if it weren't so close to the earth?

By comparing a star's absolute magnitude to its apparent magnitude, its distance may be determined. Another factor, however, that enters into this method of distance determination is the reddening of a star's light that is caused by dust that is found throughout the universe. This dust affects the color of a star as observed on the earth. Dust particles cause a reddening effect because the dust particles interfere more with light waves in the blue range of the spectrum than with light waves in the red range. As a result, the apparent light of a star can be redder than the actual light given off by that star.

In calculating a star's actual brightness, astronomers discov-

Activity Observing Magnitudes of Light Bulbs

Materials

several light bulbs of different wattages (for example, 10 watts, 40 watts, 200 watts)

2 light bulbs of the same wattage

light sockets with long cords (Table lamps without shades and with extension cords will do nicely.)

Purpose

To illustrate apparent brightness and magnitude, using light bulbs.

What to Do

1. Place the light bulbs in their sockets on a long table at one end of the room. The table should be placed so that the lamps can be slid along the table, toward and away from the observer.
2. Turn off the lights in the room and plug in the lamps on the table. Stand across the room from the table and have another student slide the lamps toward and away from you until all of them appear to be the same brightness.
3. Turn the room lights back on and observe the way the bulbs are lined up on the table.
4. Try the same activity again, keeping one eye closed. (Closing one eye prevents your mind from using parallax displacement as a way of determining distance.)
5. Mark the positions of the bulbs on the table. Then have a partner try the activity while you adjust the lamps.
6. Have someone else observe the light bulbs after you have set them up in the manner described in step 2. But have that person close one eye. (As mentioned in step 4, closing one eye prevents the mind from using parallax displacement as a way of determining distance.) With one eye closed, how do the bulbs compare in terms of brightness and distance from the observer?

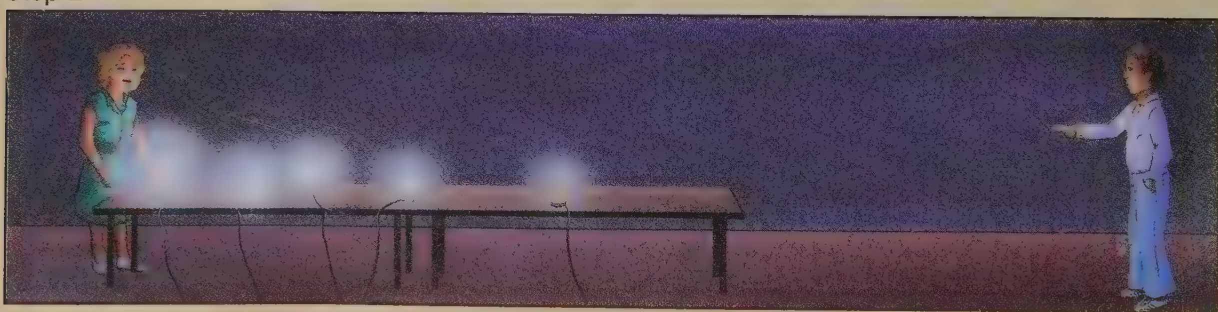
Questions

1. After your partner has arranged lamps the way you indicate, are bulbs of the same wattage next to each other?
2. Are the bulbs that have the higher wattages (and so give off more light) at the far end of the table? Are the low-wattage bulbs at the near end?
3. Does your partner's arrangement agree with yours?
4. How does closing one eye affect the conclusions of the third observer?

Conclusion

How accurate do you think classification by magnitude is?

Step 2



Star Colors and Temperatures		
Color	Class	Temperature
Blue-white	O	50 000°C
Blue	B	20 000°C
White	A	10 000°C
White	F	7000°C
Yellow	G	6000°C
Orange	K	5000°C
Red	M	3500°C

Table 4-2. Which are hotter, red stars or blue stars?

ered relationships among the colors, sizes, and temperatures of stars. 1) It was found that the color of a star is the result of its temperature. Red stars are cooler than yellow stars (our sun is a yellow-white star) and blue-white stars are the hottest of all. (See Table 4-2.) If you heated a metal bar, it would first glow red. If you continued to heat it, it would eventually become "white hot," indicating that it has a higher temperature. 2) In addition, the temperature determines the amount of light that an object gives off. The white hot metal bar would give off a great deal of light. The red hot bar would give off less light. And the bar at room temperature would give off no visible light at all. 3) Finally, a larger object gives off more light than a smaller one heated to the same temperature.

Betelgeuse (BET′-il-jooz′), one shoulder in the constellation Orion (see Figure 4-33), is a very large star. It is actually called a supergiant because of its enormous size. If you were to look carefully at Betelgeuse, you would see that it is orange-red in color. Orange-red light is relatively dim. But, being so large, Betelgeuse gives off vast quantities of its orange-red light. This is why Betelgeuse appears so bright to us, even though it is not a very hot star and is quite far away.

Rigel (RĪ′-jil), in Orion's foot, appears just about as bright to us as does Betelgeuse. But Rigel appears to be blue-white in color. This means that Rigel is much hotter than Betelgeuse. Astronomers have determined that blue-white stars like Rigel are considerably smaller than the red supergiants. Piecing all of this information together, it has been determined that although they appear to be about just as bright, Rigel is nearly twice as far from us as is Betelgeuse.

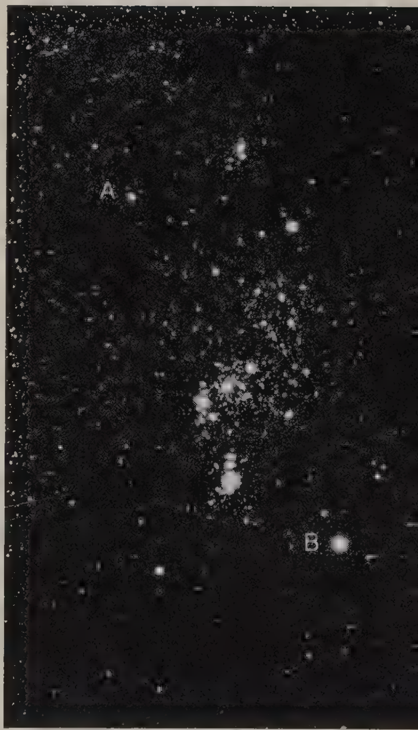


Figure 4-33. Careful observation reveals that Betelgeuse (A) is a red star and Rigel (B) is a blue-white star. In what constellation are these stars located?

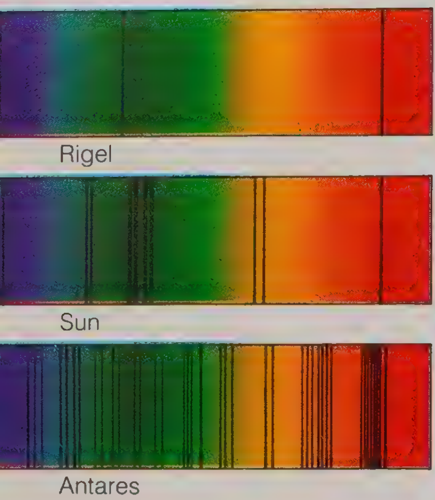


Figure 4-34. The lines in the spectrum of a star's light reveals information about the star's motion and about elements found in the star.

If an object is moving away from us, what happens to wavelengths of energy that are coming from that object?

Astronomers are also interested in the composition of stars. To find out what stars are composed of, an instrument called a **spectroscope** (SPEK′-truh-skōp′) is used. A spectroscope analyzes the light given off by stars. By allowing the light from a star to pass through a prism, the light is separated into the different colors of the spectrum. Lines in this spectrum reveal information about the elements found in the star.

The spectrum of starlight also reveals information about the motion of stars. All stars have two motions. One motion is called proper motion. The **proper motion** of a star is the change of the apparent location of the star. Because of the enormous distances between the earth and the stars, this change in position cannot be detected immediately. Astronomers must take a picture of a star and its location in relation to the stars around it. Several years later, they again photograph the star and make a comparison.

Stars also have **radial velocity.** In this second motion, the star is moving in a line toward or away from the earth. The radial velocity can be determined by examining the spectrum of a star. Astronomers have observed that the lines in the spectrum of some stars shift toward the red end of the spectrum while some stars have a spectral shift toward the violet end of the spectrum.

The cause of such a shift was first discovered with sound waves by the Austrian scientist Christian Doppler. Wavelengths from an object become longer if the object is moving away from us and shorter if it is moving toward us.

Red has the longest wavelength of the visible colors. Violet has the shortest. Therefore a shift toward the red end indicates that the star is moving away from the earth. A shift toward the violet end indicates that the star is approaching the earth. This shifting of the spectral lines is another example of the **Doppler effect.**

Check yourself

1. What are two methods of measuring stellar distances?
2. How does radial velocity differ from the proper motion of a star?

Different kinds of stars

There are many special classes of stars in the sky. One class of stars are called **Cepheid variables** (SEF′-ee-id or SEE′-fee-id). These stars get brighter and dimmer at regular intervals of time. A young astronomer named Henrietta Leavitt catalogued these special stars. She found that longer intervals between bright and dim indicate brighter stars. Cepheid variables are useful for determining the distances to stars.

Another special class of stars are called binary (or double) stars. **Binary stars** (BĪ′-ner-ee) are two stars that revolve around each other. The time that it takes for them to revolve around one another enables an astronomer to calculate their size, mass, and density.

Scientists are interested in how stars are born and how they die. They believe that stars are formed when gravitation causes clouds of dust and gases to begin to contract. This results in an increase in pressure and temperature. Eventually the temperature reaches such a high degree that a thermonuclear reaction takes place. This is the beginning of a star. It is at this point that the star begins to give off energy.

Various changes can occur as stars approach "old age." Smaller stars like our sun may expand more gradually and then collapse inward, causing a decrease in size and increase

Library research

Meteors are commonly called shooting stars. What is a meteor? What are the more common meteor showers and when do they occur?

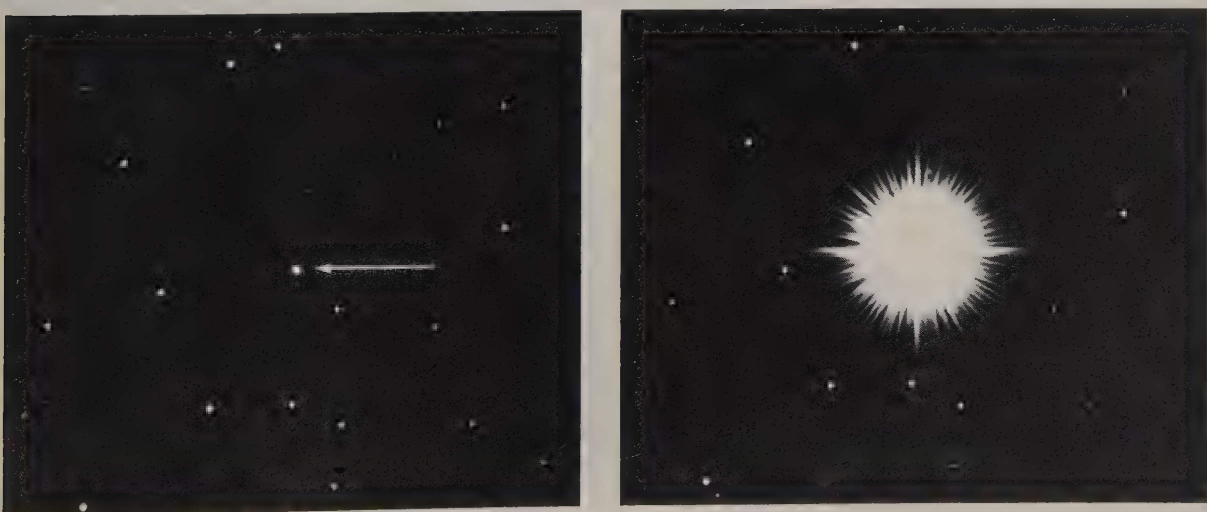


Figure 4-35. The change in brightness between left and right was caused by a nova. What is a nova?

Figure 4-36. The Crab Nebula is the remains of a supernova that was first seen in the year 1054. What is a nebula?

How large a star is a white dwarf?

in temperature. These types of stars, called **white dwarfs,** are about the size of the earth and much hotter than our sun.

A white dwarf is an old star that is not very bright. Sometimes a white dwarf becomes unstable and flares up. This temporary flare-up or outburst of a white dwarf is called a **nova** (NŌ′-vuh).

A nova is about as bright as a supergiant star. A **supernova,** which is much brighter than a nova, is produced when a supergiant star explodes.

A supernova ejects much of its matter into space, forming a huge cloud called a **nebula** (NEB′-yuh-luh). The remaining

matter collapses inward with such high pressures and temperatures that electrons and protons are fused together. The result is an incredibly dense mass of neutrons called a **neutron star** (NOO′-tron). A neutron star may be as little as ten miles in diameter and yet have a mass equal to the sun's. The density of such a star would be measured in tons per cubic centimeter.

Check yourself

1. What is unusual about Cepheid variables?
2. How do scientists believe that stars are formed?

Recent discoveries about the universe

If you looked up at the sky on a very clear night, how many stars do you think you would be able to see? Actually, on any given night you would be able to see only about 2000 stars with the unaided eye. But with a telescope, millions of stars would be visible.

Figure 4-37. This large saucerlike dish is a radio telescope. How have radio telescopes enabled scientists to expand their exploration of the universe?

Activity Simulating an Expanding Universe

Materials

balloons

8-10 circular gummed labels

Purpose

To imitate the action of an expanding universe.

What to Do

1. Slightly inflate a balloon until it has a round shape. Squeeze the end together to keep the air in the balloon.
2. Have another student paste the small gummed labels at different locations on the slightly inflated balloon. The gummed labels represent different galaxies.
3. Now continue to inflate the balloon, and observe what happens to the distance between the galaxies.

Questions

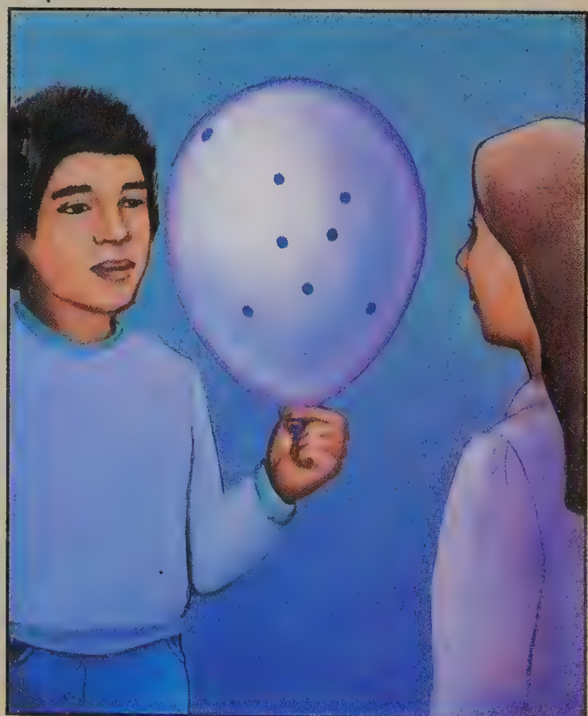
1. Compare the way galaxies move apart. How do two galaxies close to each other move in comparison with two that are far apart?
2. Do the gummed labels change size?

Conclusion

Think about what a continually expanding universe might mean. Scientists aren't sure. What do you think might happen?

Step 2

Step 3



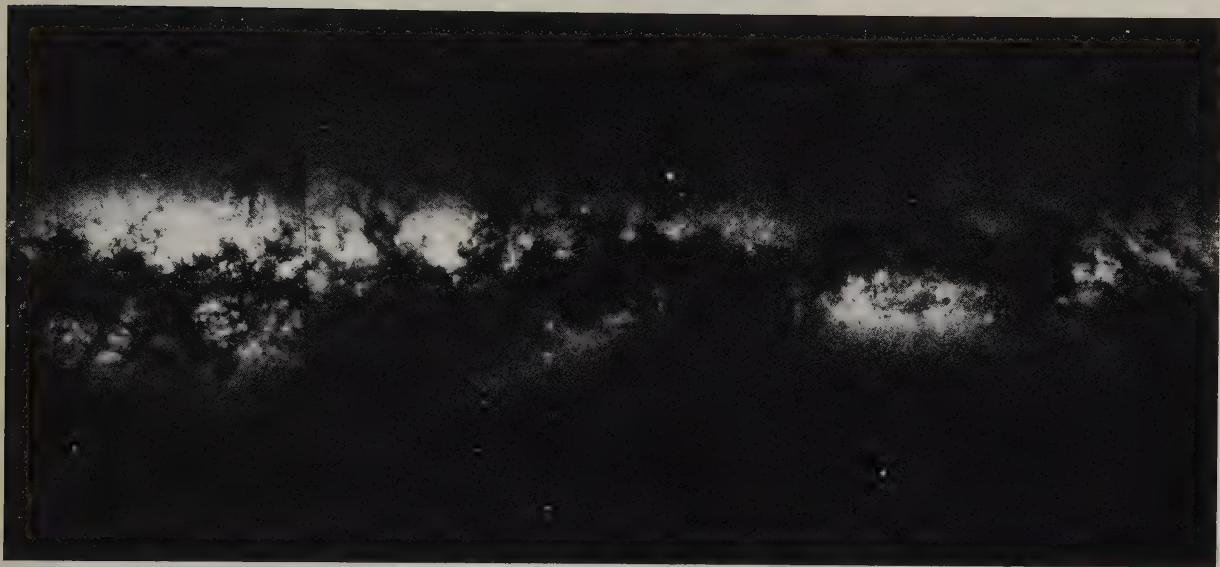


Figure 4-38. This portion of the Milky Way extends from Sagittarius to Cassiopeia.

Most of what we know about the stars and the universe has been learned from optical instruments such as telescopes, spectroscopes, and cameras. In the 1950s, a new exploration of the universe became available with the invention of the radio telescope. A **radio telescope** is a large saucerlike dish that collects radio waves from space. After many years of collecting these strange noises, the scientists were able to figure out some of the meanings.

Recently, an entirely new field of astronomy has developed. Satellite observatories have been sent high above our atmosphere with instruments that collect X-rays, gamma rays, and cosmic rays. These high-energy astronomical observatories (HEAO) have revealed a strange and violent universe. From these special observatories, astronomers have learned more about galaxies, clusters of galaxies, and the life cycles of stars.

A **galaxy** (GAL'-ik-see) is a large system of stars that is held together by gravitational attraction. In late winter, you may have seen a faint white light similar to a thin cloud stretching across the sky from the northwest to the southeast. This is called the Milky Way. What you are actually seeing is a part of the Milky Way galaxy. Our sun and the nine planets and their satellites are all part of the Milky Way galaxy.

Library research

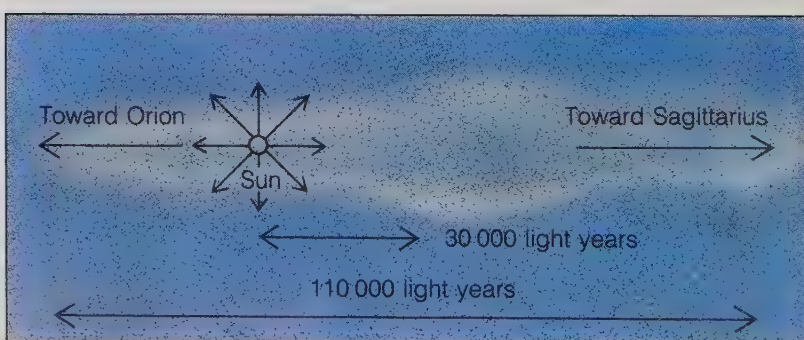
Find out more about the operation of a radio telescope. How have scientists been able to attach meaning to radio waves from outer space?

Figure 4-39. This picture is an artist's rendering of how the Milky Way galaxy would appear from outside, based on data gathered by astronomers on the earth. Our solar system lies in one of its spiral arms.

How have scientists been able to learn so much about the Milky Way galaxy?

Through careful observation, scientists have been able to learn much about the Milky Way galaxy. For example: 1) The Milky Way galaxy has a flattened spiral form. (See Figure 4-39.) Our solar system lies in one of its spiral arms. 2) Our solar system is not located in the center of the galaxy. Rather, it is 30 000 light years from the center. (See Figure 4-40.) 3) The diameter of the Milky Way galaxy is estimated to be approximately 110 000 light years. 4) Within the galaxy, there are thought to be 100 billion stars. 5) In addition to the motion of all the objects within the galaxy, there is also a spiraling motion of the galaxy itself. 6) The mass of the galaxy is considered to be 200 billion times that of the mass of the sun.

Figure 4-40. How far is our solar system from the center of the Milky Way galaxy?



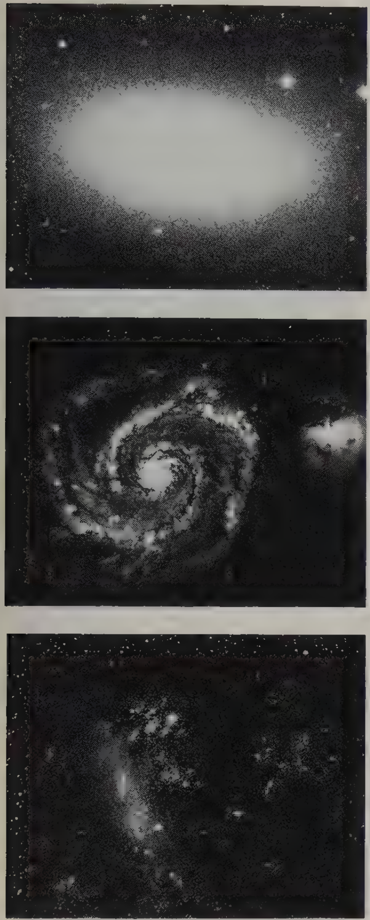


Figure 4-41. The three main types of galaxies, classified by shape. *Upper:* An elliptical galaxy—NGC 205 Nebula in Andromeda. *Middle:* A spiral galaxy—the Whirlpool galaxy in Canes Venatici. *Lower:* An irregular galaxy.

There are many galaxies within the universe, and they are found in many forms. Scientists have classified galaxies by shape. The three main classes of galaxies (shown in Figure 4-41) are elliptical, spiral, and irregular. In addition to galaxies, there are distant star clusters. A *star cluster* is a group of stars held together by gravitational attraction, but not as complex as a galaxy.

Perhaps you have heard of quasars or pulsars or black holes. These are three of the more unusual objects that have been discovered in space.

Quasars (KWAY′-sarz) appear to be the size of very large stars, but they differ because they give off energy that is comparable to a thousand galaxies. Scientists believe that quasars are moving away from the earth at almost the speed of light.

Pulsars are believed to be neutron stars that are rotating. The intensity of their radiation or radio pulses is controlled by their rate of rotation.

Black holes are something of a mystery. The most widespread theory today is that when an especially massive star uses all its fuel source, gravity causes an inward collapse of all the material that remains, forming a black hole. The matter within a black hole is so dense and the gravity so great that it prevents even light from escaping. Since no light can escape, a black hole cannot be seen. Even though scientists cannot see a black hole, they believe that black holes may exist. By means of Einstein's theory of relativity, scientists are able to explain the existence of black holes mathematically.

Scientists have theories about how our solar system was formed. They also have theories about the origin of the universe.

Scientists have theories about how our solar system was formed. They also have theories about the origin of the universe.

Albert Einstein's first model of the universe in 1917 depicted it as static and of infinite age. He assumed that a repulsive force exists between objects of the universe that exactly counteract the force of gravity. Other astronomers such as Hermann Bondi, Thomas Gold, and Fred Hoyle also support this idea that the universe appears the same at all time.

The American astronomer, Edwin Hubble, proposed a different model in 1929. According to Hubble, the universe is expanding rapidly. Hubble's theory has been nicknamed

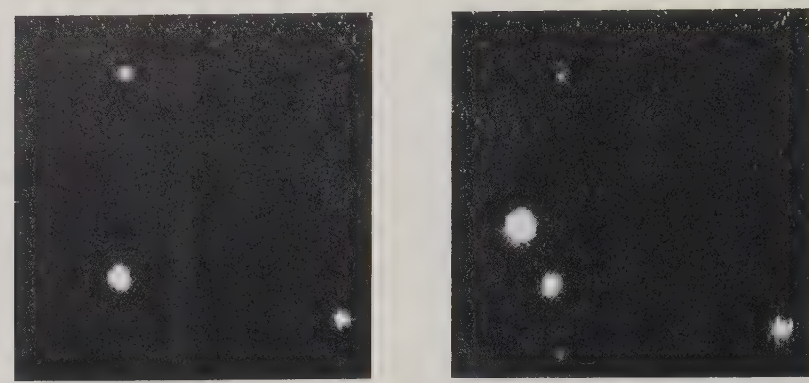


Figure 4-42. The pulsar at the center of the Crab Nebula shows a pulse that repeats every thirty seconds. What controls the radio pulse of a pulsar?

The Big Bang Theory and is receiving the most attention at the present time. Here are some of the main points of Hubble's theory.

- The universe is about 15 billion years old.
- It began as a small group of particles about the size of a pin head.
- They expanded and spread out in a fraction of a second.
- They formed a fireball of matter.
- The fireball exploded and the particles scattered.
- The entire universe was formed from this fireball.
- As the particles scattered, some came back together.
- These formed small atoms such as hydrogen.
- The atoms formed a dust cloud which expanded and cooled.
- From this dust cloud clumps of matter formed.
- The planets of the solar system probably formed about 5 billion years ago.
- The universe is still expanding.
- Galaxies are rushing away from each other at tremendous speeds.

With the new knowledge that scientists obtain from satellites and from new instruments, the next few decades may lead to a better understanding of the universe.

Check yourself

1. How have radio telescopes added to our understanding of outer space?
2. Why are black holes such a mystery?

Space exploration in our age

Figure 4-43. This photo shows the takeoff of a space shuttle.

You have already read of the developments of the *Apollo* program and landings on the moon (in Section 1). In Section 2, you read of unmanned explorations of various planets by the *Viking* and *Voyager* spacecrafts. The age in which we live has had greater advances in space exploration than any previous time. The efforts of space exploration can be divided into three different phases: First, spacecraft carrying humans, such as the *Apollo* moon exploration program; second, automated space probes containing instruments but with no humans on board, as the *Voyager* and *Viking* programs; and finally, space shuttles, which can travel between earth and space many times.

In addition to the missions, other human-carrying space expeditions include the United States *Mercury, Gemini,* and *Skylab* programs, as well as the *Vostok* and *Soyuz* programs of the Soviet Union. Except for *Apollo,* all have been orbital expeditions about the earth.

Automated, interplanetary space programs without humans on board are shown in Table 4-3.

Table 4-3: Notable Interplanetary Space Programs Without Humans on Board

Spacecraft	Nation	Launched	Accomplishments
Venera 3	USSR	1966	Entered atmosphere of Venus
Venera 4	USSR	1967	Sent temperature and chemical data from Venus
Venera 7	USSR	1970	Transmitted data from surface of Venus
Mars 3	USSR	1971	First landing on Mars
Pioneer 10	USA	1972	Flew past Jupiter; sent back scientific data
Mariner 10	USA	1973	Orbited Mercury; sent back photos
Venera 9	USSR	1975	First to photograph surface of Venus
Viking 1	USA	1975	Sent back photos and data of surface of Mars
Voyager 1	USA	1977	Flew past Jupiter and Saturn; to Uranus 1986
Voyager 2	USA	1977	Flew past Jupiter and Saturn; to pass Uranus 1986; then perhaps Neptune

Figure 4-44. The *Skylab 1* space station carried humans, who performed scientific experiments over a two-year period.

Figure 4-45. This photo shows the space shuttle *Columbia* beginning its descent in California.

The latest accomplishments have been with space shuttles. The first space shuttle, the *Columbia,* was launched by the United States on April 12, 1981, orbited the earth for two days, returned to earth, and made a safe landing. The *Columbia* and other shuttles have made many repeated orbital flights since that time.

Shuttles have launched new satellites and have enabled astronauts to repair faulty satellites presently in orbit. They have provided means for conducting many experiments in space, including the study of various biological functions.

Further advancement of the space shuttle program will make future space travel more controllable, and will make possible the construction of orbiting space stations.

Space travel in the future. Possibilities of space travel in the future are endless. The use of the space shuttle will lead toward the development of space stations, which will serve as relay points for missions that go deep into outer space. Listening devices are now searching space for evidence of other intelligent life in the universe. No doubt, attempts will be made to reach such life if it is discovered. The future of space exploration promises to be very exciting!

Check yourself

1. What are the three directions taken in space exploration in recent times?
2. What planets have been explored by space probes?
3. What use has been made of the space shuttles?

Section 3 Review Chapter 4

Check Your Vocabulary

absolute magnitude	parallax
apparent brightness	parallax angle
binary stars	proper motion
black hole	pulsar
Cepheid variable	quasar
Doppler effect	radial velocity
galaxy	radio telescope
light year	spectroscope
magnitude	supernova
nebula	true brightness
neutron star	white dwarf
nova	

Match each term above with the numbered phrase that best describes it.

1. The difference in the line of sight to an object from two different places
2. The angle that results when an object is viewed from two different locations
3. The distance that light travels in one year
4. A classification of a star according to its apparent brightness
5. The amount of light a star is giving off
6. How bright a star appears from the earth
7. Brightness of a star if 32.6 light years away
8. An instrument that analyzes light
9. Change of a star's apparent location
10. The motion of a star in a line toward or away from the earth
11. The shifting of the spectral lines of a star
12. A star that gets brighter and dimmer
13. Two stars that revolve around each other
14. The explosion of a giant star
15. The explosion of a supergiant star
16. A small star that is extremely hot
17. A huge cloud caused by a supernova
18. An incredibly dense mass of neutrons
19. Collects radio waves from space
20. A large system of stars
21. Gives off energy of a thousand galaxies
22. A rotating neutron star that gives off pulses
23. Not even light can escape from it

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The brightness of a star as seen from the earth depends upon _?_.
   a) temperature, size, distance from earth
   b) temperature and color
   c) color and distance
   d) temperature only
2. Stars that get brighter and dimmer at regular intervals are called _?_.
   a) supergiants
   b) Cepheid variables
   c) white dwarfs
   d) binary stars

Check Your Understanding

1. Why is the parallax method useful for measuring the distance of only "nearby" stars?
2. How does absolute magnitude differ from magnitude?
3. What is meant by a star's luminosity? Why is a star's luminosity difficult to calculate?
4. Why are Cepheid variables important to astronomers?
5. What is meant by the Big Bang theory?

Chapter 4 Review

Concept Summary

The **moon**, which is the earth's only natural satellite, is like the earth in some ways and unlike the earth in other ways.

- ☐ Both revolve in slightly elliptical orbits around larger objects.
- ☐ Both are thought to have similar interiors and to be about the same age.
- ☐ Unlike conditions on the earth's surface, conditions on the moon's surface (which include extremes of temperature and no atmosphere) do not promote life.

The **solar system** is the sun and all the objects that revolve around the sun.

- ☐ Various models of a solar system have been suggested throughout history.
- ☐ Many reasons favor acceptance of the present sun-centered model.

The **sun** is the star that provides the earth's energy and is the star around which all the planets revolve.

- ☐ The sun's energy is provided by nuclear fusion.
- ☐ Without the sun, there could be no life on the earth.
- ☐ Without the gravitational force of the sun, the planets would fly off into space.

A **planet** is a large object that revolves around the sun and that shines by reflected sunlight.

- ☐ The earth is one of nine planets orbiting the sun.
- ☐ The earth is the only planet known to support life.
- ☐ Information about the planets other than Earth has been obtained through the use of various instruments, including telescopes and spacecraft.

A **star** is a glowing object similar to but more distant than our sun.

- ☐ Stars vary greatly in distance, composition, size, and age.

A **galaxy** is a large system of stars that is held together by gravitational attraction.

- ☐ Our sun and solar system is part of the Milky Way galaxy.

Putting It All Together

1. Compare the earth and the moon as environments for life. Describe specific conditions that affect anything on the surface of either the earth or the moon.
2. Draw a diagram that shows the difference between a total lunar eclipse and a partial lunar eclipse.
3. Compare the observations of the moon made by Galileo and by the *Apollo* spacecraft. What kinds of data were gathered by each source? How was the data obtained by each source? How did the data gathered during the *Apollo* mission relate to the findings of Galileo?
4. What objects belong to the solar system?
5. Why are Newton's laws important to a scientific understanding of the motions of the different objects within the solar system?
6. Identify each of these planets: the largest; the smallest; the nearest to the sun; the farthest from the sun; the longest period of rotation; the shortest period of rotation; the most satellites; the planet nearest to the earth in size.
7. Describe two methods that scientists use to determine stellar distances.
8. Name different instruments used to study the stars. Tell why each different one is important to the astronomer.
9. Describe the two different kinds of motion that stars have. What methods are used to detect each different kind of stellar motion?
10. What happens at the beginning of a star? What are two different ways in which stars come to an end?

Apply Your Knowledge

1. Prepare a list of items you would take with you if you were going to the moon by yourself.
2. Make a time line to show the progress of the conquest of space.
3. Construct a bulletin board display to show the hazards of space travel.
4. Organize a debate that centers on a space-oriented question. Some examples: Is there life in outer space? Are there flying saucers?
5. Make an area on the bulletin board for space and astronomy current events. Put up interesting clippings, news headlines, and articles. Obtain an astronomical sky map and report to the class the various events that can be seen each night.

Find Out on Your Own

1. Observe the moon through binoculars or a telescope. Identify the features seen by Galileo.
2. What does the word *occultation* mean? Observe a lunar occultation. How quickly did the star disappear? How long was it occulted? Describe your findings to the class.
3. Observe a meteor shower. Prepare a report of when meteor showers occur. Make a count of how many you observed. If possible, take a time-lapse photograph.
4. Choose one planet that is visible and make an observation of that planet each day at the same time. Keep a record of its position against the star background. Explain the motion you observe.
5. Using a cardboard mailing tube or the cardboard tube from a roll of paper towels, look through the tube at the Big Dipper. Count the number of stars. Then point the tube at a section of the Milky Way and make a star count. Report your findings to the class.

Reading Further

Branley, Franklyn M. *Halley: Comet 1986.* New York: Lodestar Books, 1983.

Interesting, well-written account of comets, including Halley's.

Fields, Alice. *The Sun.* New York: Watts, 1980.

A fine reference book for learning more about the sun. Beautifully illustrated. Several simple experiments demonstrate size and distance.

Gallant, Roy A. *National Geographic Picture Atlas of Our Universe.* Washington, DC: National Geographic Society, 1980.

A fantastic book splendidly illustrated of the solar system and space exploration.

Hawkes, Nigel. *Space Shuttle.* New York: Gloucester Press, 1983.

An account of the space shuttle with excellent photographs and drawings.

Heidmann, Jean. *Extragalactic Adventure: Our Strange Universe.* New York: Cambridge University Press, 1982.

A delightful book covering such topics as evolution of the universe, relativity, space-time, black holes, and extraterrestrials.

Taylor, Paula. *The Kids' Whole Future Catalog.* New York, Random House, 1982.

Predicts what the future holds: the food we will eat, the houses we will live in, the cars we will drive, the energy sources we will have. Encourages you to think about the future and how you can prepare for it.

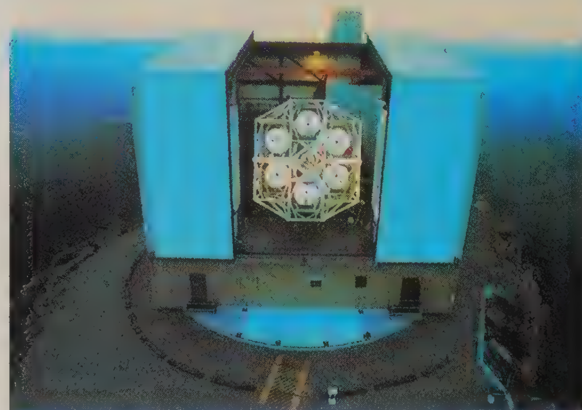
Science Issues of Today Improvements in Astronomic Observations

In 1609, Galileo was the first person to use the newly invented telescope to make astronomical observations. His improved versions of the telescope allowed him and other naturalists to make the basic discoveries that led to the modern science of astronomy.

Always wanting to reach out further, astronomers have designed larger and more powerful telescopes. Telescopes use sophisticated lenses and mirrors that have to be precisely ground and polished to provide distortion-free images. Light-gathering ability and magnification increase with larger-diameter mirrors. The larger-diameter mirrors have traditionally been very thick and heavy because a large mirror that is too thin will eventually bend, deform, and lose its usefulness.

Even though some astronomers have sensing devices that measure types of radiation such as radio waves and X-rays, the need to reach out further for optical images still continues. For many years the 200-inch diameter mirror at Mount Palomar Observatory in California was considered the largest possible size for a telescope; the mirror alone weighed over 14 tons, and the entire instrument about 500 tons.

However, with the advent of space age materials and new designs, even more powerful telescopes are now being built. One method of making larger mirrors that are strong and much lighter in weight is to make the back surface like a honeycomb. Another technique is to use multiple mirrors which are aimed and synchronized by using computer control. One telescope of this type is currently in operation in Arizona. It uses four 295-inch mirrors and has the equivalent total light-gathering capacity of a 590-inch mirror. Two other powerful telescopes with completion dates of 1989 and 1996 are under construction; one is in west Texas and the other is in Hawaii. These telescopes will have the capabilities of 300-inch and 400-inch mirrors. A 300-inch mirror has over twice the light-gathering capacity of a 200-inch mirror!



The six 72-inch mirrors of this telescope view the sky from Mount Hopkins, near Tucson, Arizona. The images of the joint Smithsonian-University of Arizona telescope are coordinated by a sophisticated video system.

The atmosphere is another limiting factor for telescopes because light forming the images is often distorted as it travels to the earth's surface. The best optical observatory should be located above the Earth's atmosphere, perhaps even on the moon. With the increasing effective size and decreasing weight of mirrors, a moon-based observatory may become a reality in the twenty-first century.

All the improvements in astronomic observations provide an increased understanding of our universe and how it formed. This is one of the most exciting frontiers of modern science.

Air in Motion

Unit 3

Above the "solid" earth are two kinds of fluids. One fluid, water, fills the lakes, rivers, and oceans. The other fluid is the one that all of us live under—the gases that make up the atmosphere.

Without the earth's atmosphere, there could be no life on the earth. The earth's atmosphere filters out certain rays from the sun which are harmful. The earth's atmosphere contains the gases needed by living organisms. Much of the recycling and redistribution of the earth's water takes place in the earth's atmosphere.

Chapter 5

The Atmosphere

Section 1
Heat and the Atmosphere

Without heat, temperatures on the earth would be far too cold to provide an environment for life.

The earth receives most of its heat from the sun. Even though the earth receives only a small portion of the total energy given off by the sun, the energy received is enough to power a life-supporting system.

The earth does more than just receive solar energy. It must also process that energy. This important function is performed by the earth's atmosphere.

Section 2
Winds and the Atmosphere

The atmosphere not only processes incoming energy. It also acts as a circulating system.

The air in the atmosphere is a fluid which can move from one place to another. These movements of air, which are caused by unequal heating of the earth's surface, are called winds. Winds affect temperatures around the earth.

Section 3
Moisture and the Atmosphere

Heat causes warmth. Heat also causes motion in the atmosphere.

Motion in the atmosphere can bring a warm breeze during cold weather or a cooling breeze during a hot spell. It can also bring the moisture needed to support life.

Heat powers the winds. It also powers the water cycle, causing water to enter the atmosphere in the form of invisible water vapor which later condenses and forms the raindrops and snowflakes that replenish the earth's supply of fresh water.

The clouds in the picture on the facing page are made up of water droplets that condensed because of a change in air temperature above the earth's surface. But most of the atmosphere is invisible. What can you learn about the invisible atmosphere through your senses of smell, touch, and hearing?

Heat and the Atmosphere Section 1

Section 1 of Chapter 5 is divided into five parts:

Energy from the sun

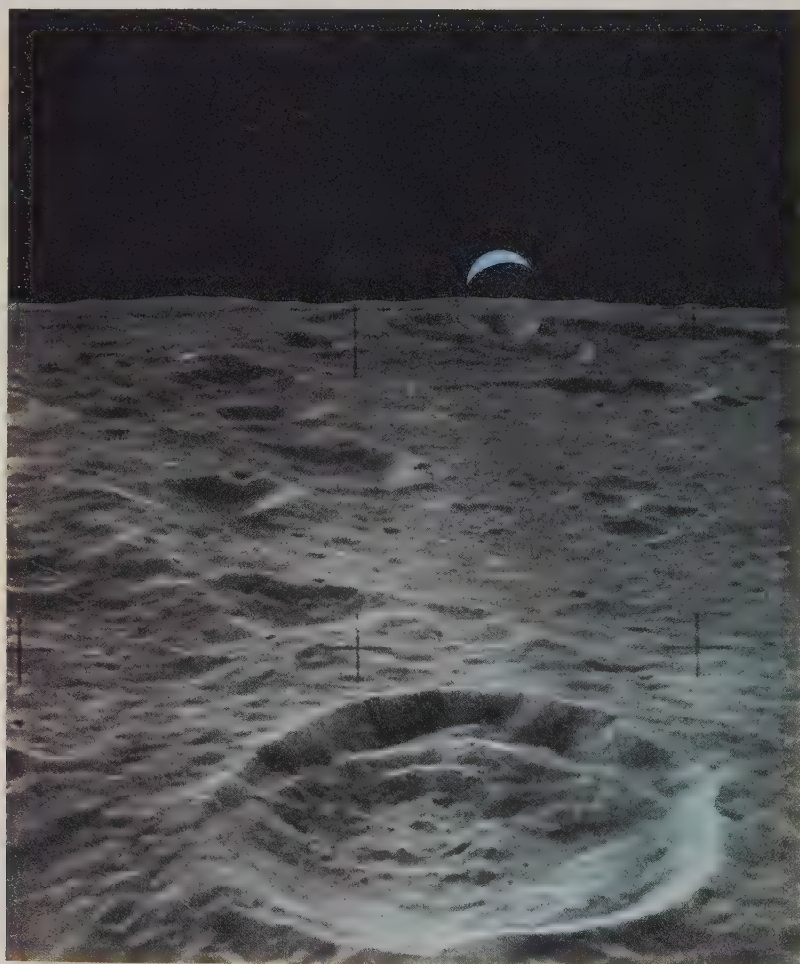
Energy moves by conduction

Energy moves by convection

Energy moves by radiation

Temperatures around the earth

Figure 5-1. This photograph, taken by *Apollo 14*, shows the earth rising above the moon's surface. Conditions on the surface of the moon, which has no atmosphere, are very different from conditions on the earth's surface. How does the earth's atmosphere affect conditions on the earth's surface?



Almost all the earth's energy comes from the sun. Without the sun, the earth would be a frozen wasteland. Surface temperatures would be hundreds of degrees below zero. Without the sun, there could be no life on earth.

Without the atmosphere, there could be no life on earth either. The **atmosphere** is the blanket of air that surrounds the earth. Air is a mixture of several different gases. On dry days, the air in the atmosphere is about ⅘ nitrogen and ⅕ oxygen. The air also contains tiny amounts of carbon dioxide, hydrogen, argon, and other gases. Another important gas found in the air is water vapor. The amount of water vapor in the atmosphere varies, depending on weather conditions.

The atmosphere is important because it filters out harmful parts of the incoming energy from the sun. The atmosphere is important because it absorbs and stores up useful energy that would otherwise be lost. The atmosphere is also important because it provides a means by which energy can be recycled and circulated around the earth.

How does the atmosphere affect the energy the earth receives from the sun?

Energy from the sun

The sun's energy that reaches the earth's atmosphere is only a small part of the energy that leaves the sun. The sun sends out energy in all directions. Yet this energy is so strong that the earth, which is about 150 million kilometers from the sun, receives enough energy to support life.

The sun's energy is carried through space by waves. These waves are similar to the waves that are produced when an electric current moves back and forth through the coil of an electromagnet. Therefore they are called **electromagnetic waves.**

As shown in Figure 5-2, waves can be of different sizes. It may help you to understand this better if you think in terms of water waves. Imagine water waves on a lake or ocean. Sometimes the waves are large and sometimes they are small. The distance between waves also differs from time to time. The distance between waves, which is measured from the top of one wave to the top of the next wave, is called a **wavelength.** In Figure 5-2, the wavelength of Wave A is twice as long as the wavelength of Wave B.

Figure 5-2. Waves can be of different sizes. How do the lengths of Waves A and B compare?

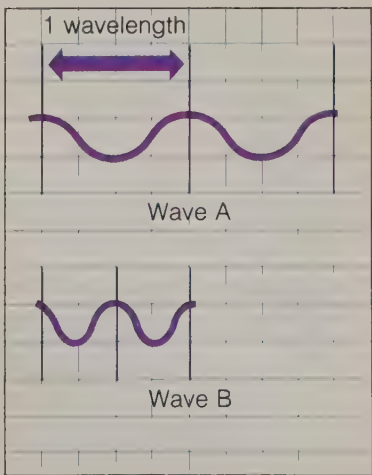
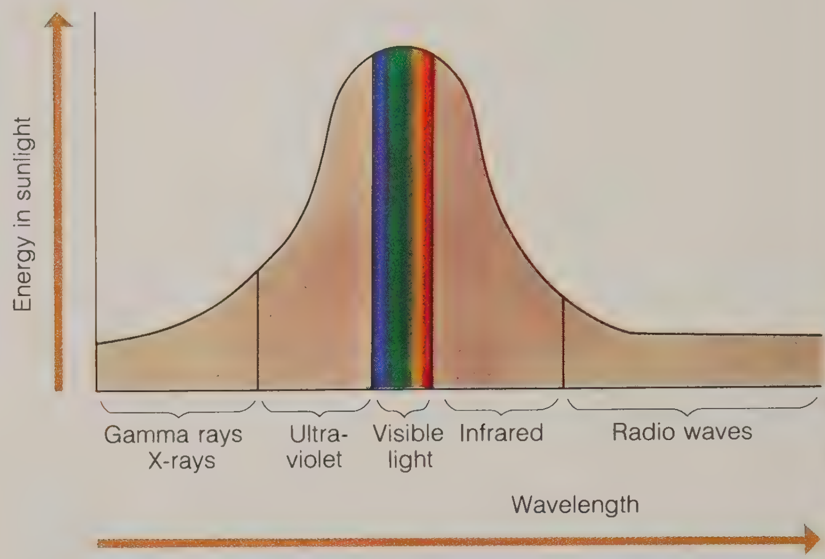


Figure 5-3. The electromagnetic spectrum contains energy waves of many different wavelengths. What kind of electromagnetic waves carry the greatest amount of energy in sunlight?



Library research

Prepare a report on the different zones within the earth's atmosphere. What are the various zones? How does each zone differ from the others? How has the data on each zone been obtained?

How harmful are gamma rays and X-rays?

Energy from the sun comes in waves of many different wavelengths. The energy waves of all the different wavelengths together make up what is called the **electromagnetic spectrum.** Figure 5-3 shows the different energy waves in the electromagnetic spectrum. It also shows that the electromagnetic waves of visible light (the thin band in the middle of the diagram) carry the greatest amount of energy in sunlight.

Figure 5-4 shows what happens to the sun's energy that reaches the earth's atmosphere. Part of the sun's energy is reflected back into space. This is caused when incoming energy strikes dust particles or water droplets that are present in the atmosphere. (It is these dust particles that cause light to be scattered, thus giving the sky its blue appearance.) The amount of incoming energy that is reflected back into space in this way is very small.

Part of the sun's energy is scattered throughout the atmosphere. This scattering is caused by dust particles, by water droplets, and by molecules present in the atmosphere.

Part of the sun's energy is filtered out by the atmosphere. Gamma rays and X-ray waves, which would kill people, are filtered out before they reach the earth's surface. Ultraviolet waves, which produce suntans and sunburns, are also partially filtered out. Otherwise, human life would be shortened, particularly for people whose skin is sensitive to sunburn.

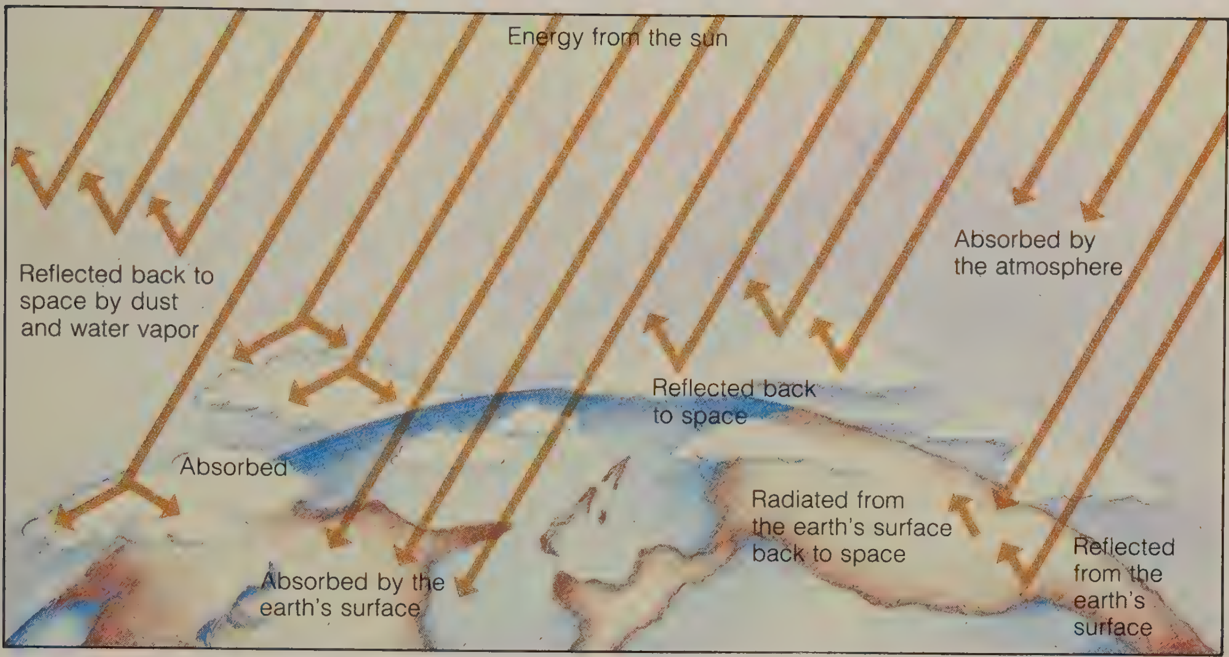


Figure 5-4. What would happen if energy waves like gamma rays and X-rays were not filtered out by the atmosphere?

Part of the sun's energy reaches the earth's surface and is absorbed. If you have ever touched a metal surface that is in direct sunlight you have experienced an example of a solid material that has absorbed energy from the sun.

Check yourself

1. What effect does the earth's atmosphere have on incoming energy waves from the sun?
2. How necessary is the atmosphere for life on the earth? Give examples.

Energy moves by conduction

Energy moves in one of three ways. 1) Energy can move through a material, usually a solid object, without the material itself moving. This way of moving is called **conduction.** 2) Energy can move through a material such as a liquid or a gas because of some movement within the material. This way of moving is called **convection.** 3) Energy can move through empty space, or through a material such as air, water, or glass without the aid of the material. This way is called **radiation.**

Our Science Heritage

How Does the Sun Produce Energy?

From earliest times, people have realized the importance of the sun. Without the light and heat from the sun, there could be no life on earth. Because the sun is so necessary, some people have considered the sun to be a god.

How does the sun produce energy? Various explanations have been suggested.

At one time, it was thought that the sun was a mass of burning material, sending out heat and light as if from a huge bonfire. But this explanation cannot be true. If the sun's energy were produced by burning, the sun would burn itself out in about two years.

Other theories were also suggested. Some people thought that the release of energy was caused by meteors crashing into the sun. In the 1800s, a theory was developed that the sun's energy was produced by a gradual shrinking of the sun.

It was not until the 1900s that scientists developed a theory of how the sun, which is thought to be over four and a half billion years old, could continue to produce such huge amounts of energy over so long a period of time.

Scientists now believe that the sun produces energy by a process of nuclear fusion. Much of the sun is made up of hydrogen gas. The heat and the force of gravity at the center of the sun are so great that particles within atoms of matter are rearranged. Atoms of one element are changed into atoms of another element which has less mass. In the process, some matter is changed into energy.

The discovery that matter can change into energy is one of the key scientific discoveries of the twentieth century. The work of many twentieth-century scientists has been concerned with the atomic structure of matter and with the relationship between matter and energy.

As for how the sun produces energy, you might want to find out more about Hans Bethe, a scientist who won the Nobel prize in 1967 for his work on energy production of stars.

When energy moves by conduction, it moves through a material without the material itself moving. If a metal bar is heated at one end, the other end will soon become hot. Heat, which is

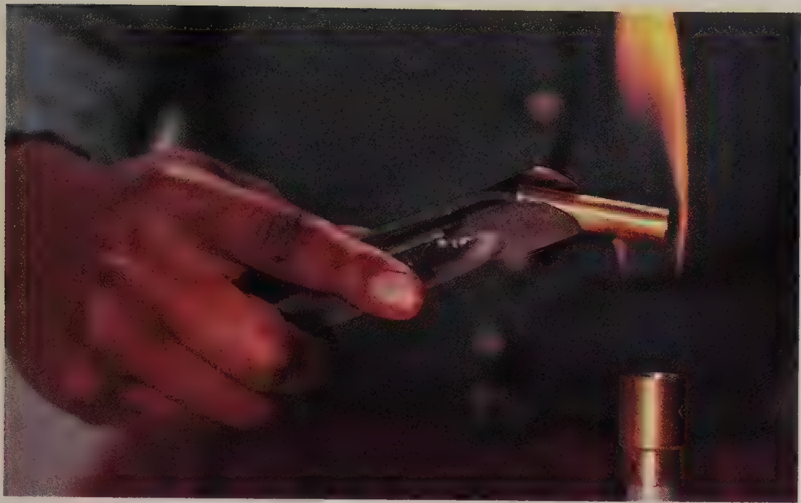


Figure 5-5. Heat energy can move through solid material by means of conduction. Eventually, heat from the flame will warm the metal pipe, then the end of the metal tongs near the pipe, and then the handles of the tongs.

a form of energy, has been transferred from one end of the bar to the other by means of conduction. Conduction can also take place when two different things touch each other, such as a finger touching an ice cube.

Energy is transferred by conduction when fast-moving atoms or molecules of a material strike other nearby atoms and molecules. That is why energy is transferred by conduction best through a solid material. In a solid material, the atoms and molecules are closer together than they are in a liquid material or in a gas.

Heat is a form of energy. When something is heated, it is taking in energy. When you heat the end of a metal bar, heating causes the atoms in the heated end of the metal bar to speed up. These atoms strike other atoms nearby, causing them to speed up. This process continues all along the bar. In a short time, the atoms all the way along the bar are moving faster, too. The entire bar has become hot. Energy, in the form of heat, has been transferred from one end of the metal bar to the other end by means of conduction.

Check yourself

1. Why is energy by conduction best transferred through a solid material?
2. Describe an example of energy transfer by conduction.

Figure 5-6. Warm air rises because it is forced upward by cooler air, which has greater density.

Energy moves by convection

When energy moves by convection, it moves through a material because of some movement within the material. Convection occurs in fluids. A **fluid** is any material that can move and change shape without separating. Gases and liquids are fluids.

Convection occurs when a fluid is heated. Heating causes the atoms and molecules of a fluid to spread out. When this happens, the fluid increases in volume. But its mass remains the same, since no new matter is added. You may recall the formula

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

When a fluid increases in volume but not in mass, the fluid becomes less dense.

When a fluid is heated in one area, the portion of the fluid that is nearest the source of heat becomes less dense. (See Figure 5-6.) Gravity exerts more force on the rest of the fluid, which has greater density. The denser portion of the fluid is pulled down in under the less dense portion of the fluid, forcing the less dense portion to rise. A fluid with a low density can float on a more dense fluid.

Figure 5-7. A hot-air balloon rises because the hot air in the balloon is less dense than the cooler air outside the balloon.

The unequal densities caused by the unequal heating of a fluid cause what is called a **convection current.** Convection currents occur in oceans and lakes. Convection currents also occur in the atmosphere, where they cause winds. A hawk or condor can soar and glide great distances, carried along on convection currents of air.

What causes the convection currents that occur in fluids like the atmosphere and bodies of water?

Check yourself

1. Compare convection and conduction. How are they similar? How are they different?
2. Describe the causes of a convection current.

Energy moves by radiation

When energy moves by radiation, it moves without the aid of any material it is passing through. Light and heat are both forms of energy. Light and heat from the sun are examples of energy that moves by radiation. Light from a light bulb is also an example of energy that moves by radiation.

Inside a light bulb is a very fine wire called a filament, which is surrounded by an empty space or a vacuum. When the light bulb is turned on, electricity causes the filament to heat up to a very high temperature. Because the filament has become warmer than its surroundings, it emits—or sends out—energy by means of radiation. The heated filament emits energy in all directions—through the empty space and through the atmosphere outside the bulb. In other words, it radiates energy. Most of the energy from a light bulb is in the form of visible light. But some energy is also emitted in the form of invisible light.

If any object that is warmer than its surroundings will emit radiation, does that mean that the earth emits radiation? Absolutely. The surface of the earth, which is warmed by energy from the sun, emits radiation back into the atmosphere (shown in Figure 5-4). The reason you can't see this radiation is because the earth's surface is not hot enough to emit energy in wavelengths that are visible.

Figure 5-8. How is a light bulb like the sun?

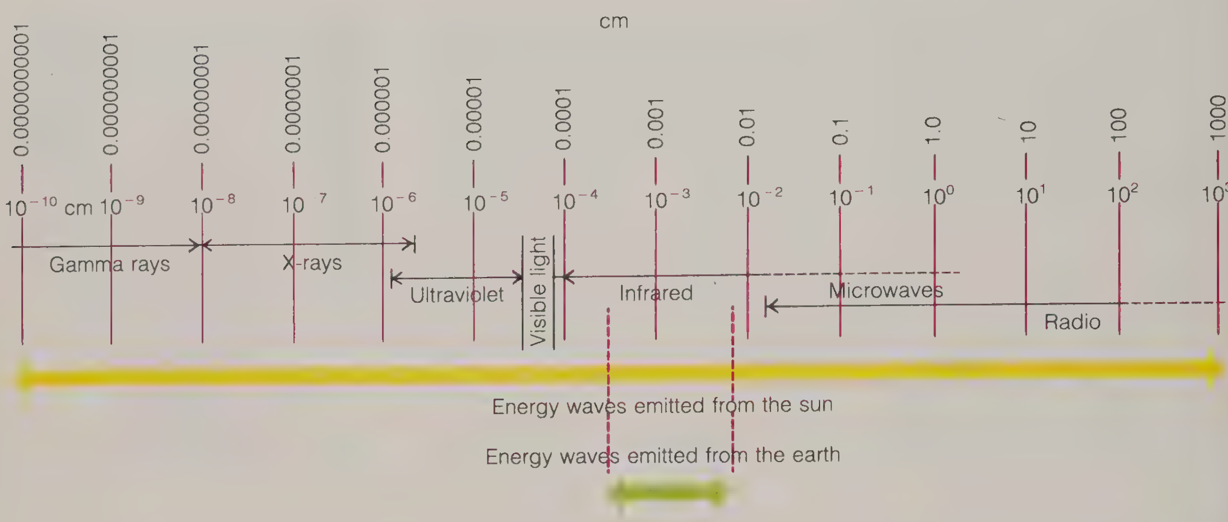


Figure 5-9. Like the sun, the earth also emits energy waves. But you can't see the energy waves emitted from the earth. Why can't you see them?

What would happen if the earth radiated energy in the same wavelengths as the energy it received?

Not all wavelengths of energy can be seen. Some are too long or too short to be visible to the human eye. In general, wavelengths become shorter as the temperature increases. Figure 5-9 shows the wavelengths of energy waves emitted from the run (from the shortest, on the left, to the longest, on the right). As you can see from the diagram, the energy waves radiated from the earth are in the infrared range and are not visible to the human eye. The wavelengths of the energy waves emitted from the earth are longer than those of energy waves in the range of visible light.

The longer wavelengths of energy emitted from the earth play an important part in maintaining comfortable temperatures on earth. The shorter wavelengths emitted from the sun pass through the earth's atmosphere and reach the earth's surface. If the earth radiated back the energy in the same wavelengths, most of the energy would pass back out into space. The longer wavelengths of energy radiated by the earth are absorbed by gases like carbon dioxide and remain in the atmosphere. This is called the **greenhouse effect** because a greenhouse traps heat in a similar way.

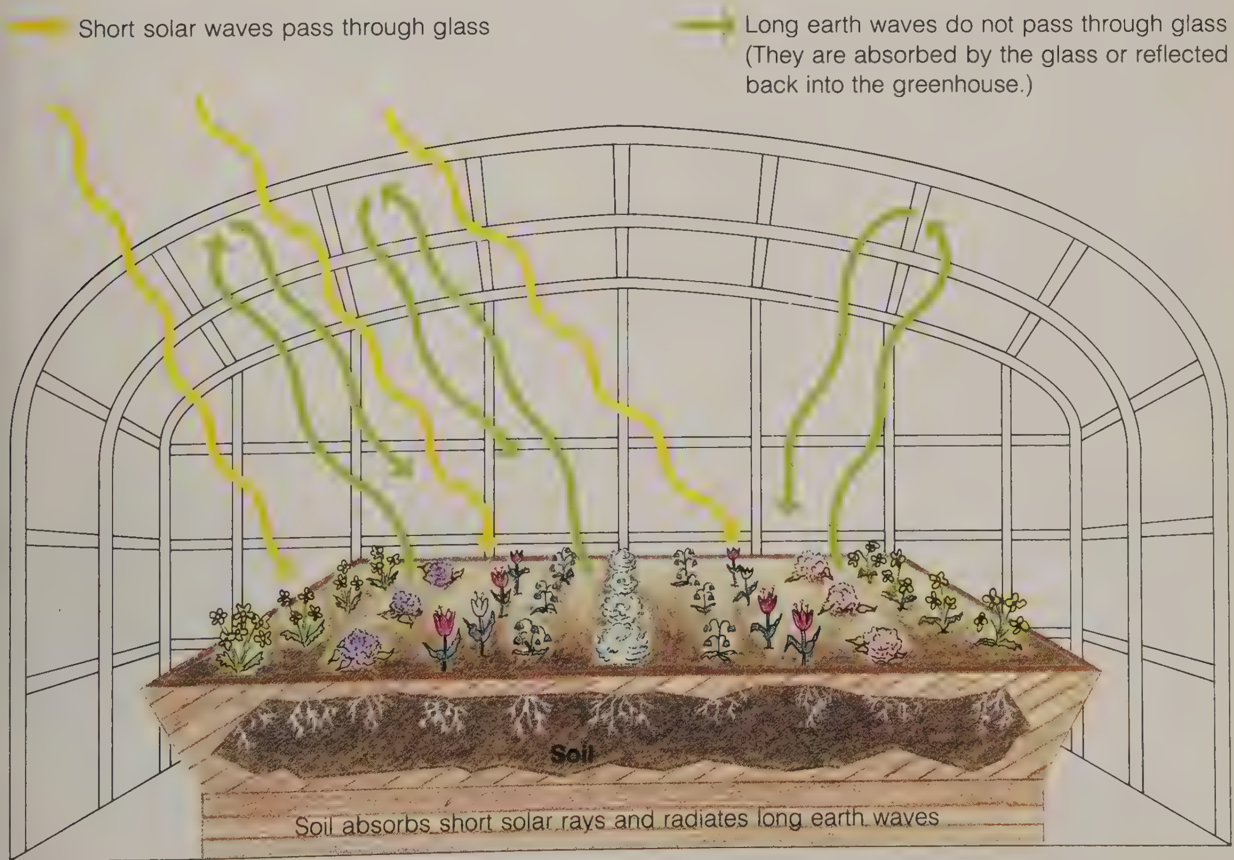
In a greenhouse, the short wavelengths of energy from the sun pass through the glass and into the greenhouse. Some of this energy is absorbed by the plants, the soil, and other objects in the greenhouse and then radiated back into the air. The energy radiated from the objects in the greenhouse has longer

wavelengths than sunlight because the objects have a much lower temperature than the sun. These longer wavelengths cannot pass through the glass. The energy in these longer wavelengths is trapped inside the greenhouse where it heats the air. That is why the temperature inside a greenhouse is usually warmer than the temperature of the air on the outside.

In the atmosphere, the greenhouse effect occurs all over the earth. Because of the greenhouse effect, the earth remains a comfortable place to live. Without the greenhouse effect, the average temperature at the earth's surface would be much colder.

Some scientists are concerned that the greenhouse effect may increase to a dangerous degree in the future. The amount of carbon dioxide in the atmosphere is slowly increasing. The increase in carbon dioxide causes an increase in the greenhouse effect. Carbon dioxide is released by the respiration of

Figure 5-10. Why is the temperature inside a greenhouse usually warmer than the temperature of the air on the outside?



How do plants, as they make food for themselves, affect the amounts of carbon dioxide and oxygen in the atmosphere?

animals and by the burning of fuels. Carbon dioxide is removed from the atmosphere by plants during the food-making process. The plants give off oxygen, which is taken in by animals. These two processes together are known as the **oxygen-carbon dioxide cycle.** For hundreds of millions of years, the amounts of both these gases have remained about the same, until recently. Now, however, people are burning many more fuels than they used to—in automobiles, in factories, and in homes. More carbon dioxide is being put into the air than ever before. As we reduce the number of trees and plants and make more concrete roads and shopping malls, there are less plants to remove carbon dioxide from the atmosphere.

Check yourself

1. How is radiation similar to conduction and convection? How does it differ from conduction and convection?
2. Describe the greenhouse effect.

Temperatures around the earth

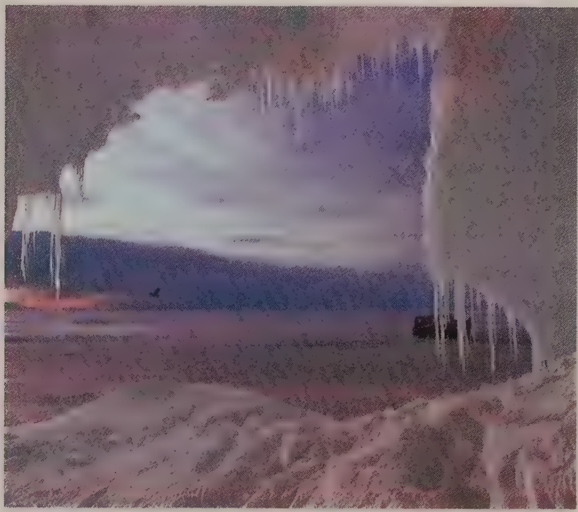
The temperature of the air at the earth's surface depends very much on energy from the sun. Energy from the sun warms the earth's surface. Energy from the earth's surface warms the atmosphere.

Air temperatures vary greatly from one place to another on the earth. The air temperature at the equator is much hotter than it is at the North or South Pole. And air temperatures at the same place change from hour to hour and from season to season. Among the causes for differences in air temperature are 1) the angle at which the waves of energy from the sun strike the earth and 2) the number of hours of daylight.

The angle at which the sun's energy strikes the earth's surface affects the amount of energy, and therefore heat, that is received. Near the equator, the sun is more nearly overhead. The angle at which the sun's energy hits locations near the equator is closer to 90°. (See Figure 5-12.) Loca-

Library research

What methods of heating buildings are used around the world? (Look for some unusual ones, too.) How do the different methods compare from one area to another? Why is one method more likely than another in a particular area? How do the different methods compare in terms of energy efficiency?



tions near the equator, therefore, receive much energy and have high temperatures.

Near the North and South Poles, the sun's energy strikes the earth's surface at a small angle (and sometimes not at all). The same amount of energy is spread over a much larger area. This results in less heat and therefore lower temperatures. As the angle of the sun's rays of energy decreases from 90°, the amount of energy received at any location also decreases.

At any location, the angle of the sun's rays of energy changes during the day. In the morning, the angle is small. The angle increases until about noon. Then the angle begins to decrease again. This results in temperature changes throughout the day.

Air temperature is also affected by the number of hours of sunlight. In summer, there are more hours of sunlight per day. As the number of hours of sunlight increases, the amount of energy received from the sun also increases.

Figure 5-11. The angle at which the sun's energy strikes the earth's surface affects the amount of energy, and therefore heat, that is received. Northern California (left) receives more energy than Antarctica (right).

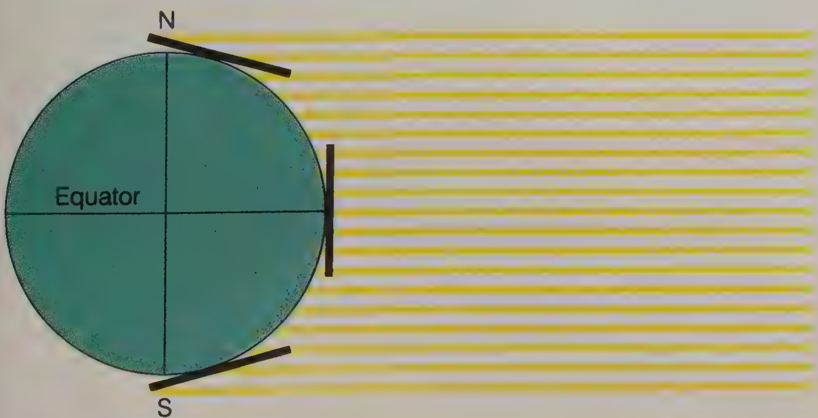


Figure 5-12. Rays of energy from the sun strike the earth's surface at different angles, depending on location and time of year. How does the angle near the equator compare with the angle near the North or South Pole?

Activity Changing the Angle of Incoming Energy

Materials

flashlight
piece of graph paper

Purpose

To see how the angle of incoming light affects energy received.

What to Do

1. Place the paper on a table or other flat surface. Make sure that the shades or blinds are drawn and lights are dimmed or turned off.
2. Shine the flashlight directly at a surface so that the light strikes the surface at a 90° angle.
3. Move the flashlight so that the light strikes the surface at a smaller angle.

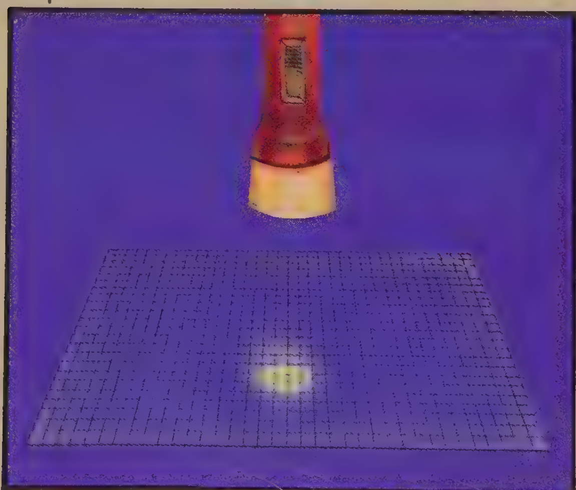
Questions

1. What does the light look like when it strikes the paper at a 90° angle?
2. How does change in angle affect the size of the lighted area? the brightness of the lighted area?

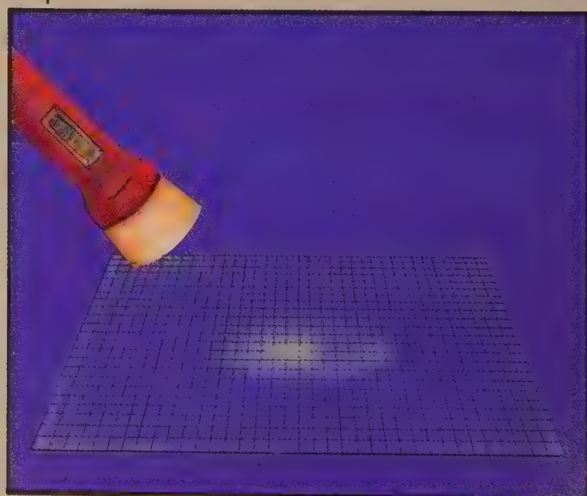
Conclusion

Is the total energy striking the paper the same both at 90° and at a smaller angle? Does the amount of energy striking the paper at any particular point change when the angle changes?

Step 2



Step 3



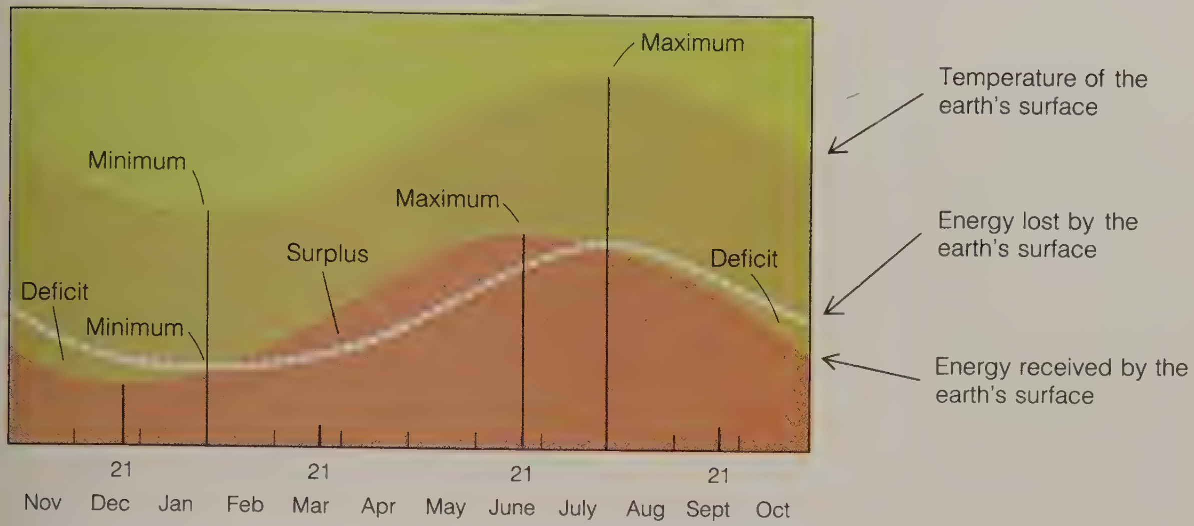


Figure 5-13. Why is there a time lag between maximum energy received and maximum temperature?

Figure 3-28 on page 159 shows the pattern of the sun's apparent path during the year over the mid-latitudes of the Northern Hemisphere. As the sun's path increases in height, the angle of the sun's rays of energy gets closer to 90°. As the sun's path gets longer, the hours of sunlight increase. In December at the mid-latitudes, the sun appears to travel on a path that is short and low in the sky. By March, the path is higher and longer. This means that the same area is now receiving energy that is stronger since the angle has increased. The area is also receiving energy for a longer period of time each day since the hours of sunlight are increasing. For both of these reasons, temperatures in the same Northern Hemisphere location are warmer in March than they were in December.

Why, in the Northern Hemisphere, are temperatures warmer in March than in December?

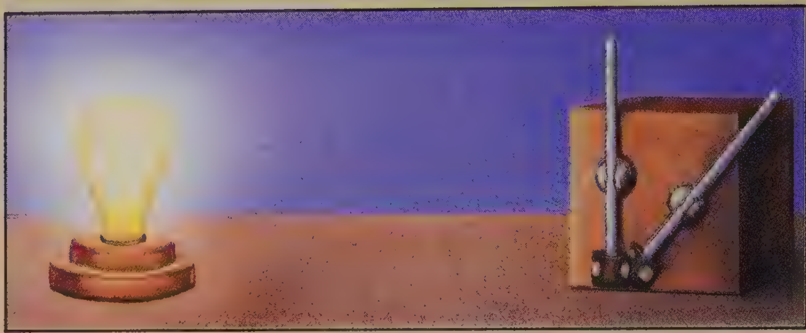
North of the equator, the sun's path is longest and highest on June 21-22. The heating effects of the sun should therefore be greatest at that time. But, as Figure 5-13 shows, the highest temperatures do not occur until around the beginning of August. This is because the earth's temperature also depends on a third factor, the rate at which the earth's surface loses energy by radiating it back into the atmosphere.

As shown in Figure 5-13, between January and June in the Northern Hemisphere, the earth's surface receives more energy than it loses. There is a surplus of energy, which becomes stored in the earth's surface. After June 21, this stored energy keeps building up for about six weeks. Even though the days are getting shorter during this period, they are still longer than the nights. The angle of the sun's rays is still very high. During this period, therefore, average temperatures continue to rise

Activity Measuring the Effect of the Angle of Incoming Energy

Materials

2 thermometers
3-cm-wide strip of black construction paper
clock or watch
modeling clay
light source with 100-watt bulb
wooden block
cellophane tape



Purpose

To see how the angle of light coming from the sun affects heating at the earth's surface.

What to Do

1. Cut 2 pieces, each about 6-cm long, from the strip of black construction paper.
2. Fold the pieces in half and tape them over the bulbs of the thermometers. As shown in the illustration, the paper should cover each bulb. The paper provides a larger surface for absorbing energy.
3. Set up the equipment as shown in the illustration. Use the clay to hold the thermometers against the wooden block. One thermometer should stand vertically. The other should be at a smaller angle. The light source should be placed about 30 cm from the thermometers.
4. Set up a chart to record the temperature of each thermometer at one-minute intervals.
5. On the chart, record the starting temperature of each thermometer.
6. Turn on the light source. At the end of one minute, read and record the temperatures again. Do not turn the light off.
7. Continue taking readings every minute for ten minutes.

Questions

1. Which thermometer indicated the greater change?
2. What appears to be the relationship between heating and the angle of incoming energy?

Conclusion

Look at Figure 5-12. On the earth, the angle of the sun's rays becomes smaller as we move from the equator to the poles. How does this relate to what you observed with the thermometers?

until a balance is reached between energy received and energy lost by the earth's surface, usually early in August. Temperatures begin to drop only after this balance has been reached.

Figure 5-14. Because of a deficit between energy lost and energy received, the earth's surface continues to cool even after energy from the sun begins to increase.

From September to December, the earth begins to lose this stored energy. Beginning on December 21-22, energy from the sun begins to increase again. But because of the deficit between energy lost and energy received, the earth's surface continues to cool for another six weeks. It takes six weeks of increased energy (from December 21 to the end of January) before a balance of energy is reached and the earth's surface starts to warm up again.

This same kind of time lag occurs on a daily basis. Though the angle of the sun is greatest in the noon position, maximum temperatures do not occur until early afternoon. During the morning, the earth's surface receives more energy than it loses through radiation. This causes a heat surplus that is stored in the earth's surface until incoming energy and outgoing energy reach a balance and the earth's surface begins to cool.

Do highest daily temperatures occur at noon, when the sun's rays are the strongest?

Temperatures at the earth's surface, therefore, depend on three factors: 1) the angle of the energy waves coming from the sun, 2) the number of hours of sunlight, and 3) the balance between energy received by and lost by the earth's surface.

Check yourself

1. How do day length and the angle of the sun's rays affect air temperatures on the earth?
2. Why is there about a six-week time lag between the first day of summer and the highest average temperatures? between the first day of winter and the lowest average temperatures?

Section 1 Review Chapter 5

Check Your Vocabulary

atmosphere
conduction
convection
convection current
electromagnetic spectrum
electromagnetic waves
fluid
greenhouse effect
oxygen-carbon dioxide cycle
radiation
wavelength

Match each term above with the numbered phrase that best describes it.

1. The blanket of air that surrounds the earth; mainly nitrogen (4/5) and oxygen (1/5)
2. Energy waves similar to the waves produced by an electromagnet; how the sun's energy travels
3. The distance between waves, which is measured from the top of one wave to the top of the next wave
4. The energy waves of all the different wavelengths of energy from the sun
5. The movement of energy through a material without the material itself moving
6. The movement of energy through a material because of some movement within the material
7. The movement of energy through a material without any aid from the material
8. Any material that can move and change shape without separating
9. The movement of a fluid caused by unequal densities of portions of the fluid that have been heated unequally
10. The warming of the atmosphere that takes place because gases in the atmosphere are able to absorb energy in the wavelengths in which it is radiated from the earth
11. The cycling of oxygen and carbon dioxide that takes place in the atmosphere

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Almost all the earth's energy comes from ?.
   a) water
   b) the sun
   c) the earth's interior
   d) carbon dioxide
2. Metal heats up after being left in the sun because it takes in or ? energy from the sun.
   a) reflects
   b) radiates
   c) emits
   d) absorbs
3. ? are fluids.
   a) Only gases
   b) Only liquids
   c) Solids and liquids
   d) Liquids and gases
4. Any object that is warmer than its surroundings will ?.
   a) absorb heat
   b) reflect heat
   c) emit radiation
   d) become denser

Check Your Understanding

1. List six things that happen to the sun's energy waves that enter the earth's atmosphere.
2. Give examples of energy transfer by convection, by conduction, and by radiation that occur naturally among earth materials.
3. How would an increase in carbon dioxide in the atmosphere affect air temperatures?
4. The earth's surface radiates heat back into space. Because of this, the highest and lowest daily temperatures do not occur when a person might expect them to. Explain.
5. What effect does the earth's radiating heat back into space have on the average highest and lowest yearly temperatures?

Winds and the Atmosphere Section 2

Section 2 of Chapter 5 is divided into five parts:

Convection currents and wind belts

Specific heat and convection currents

Atmospheric pressure and winds

The density of the atmosphere

Reading an atmospheric pressure map

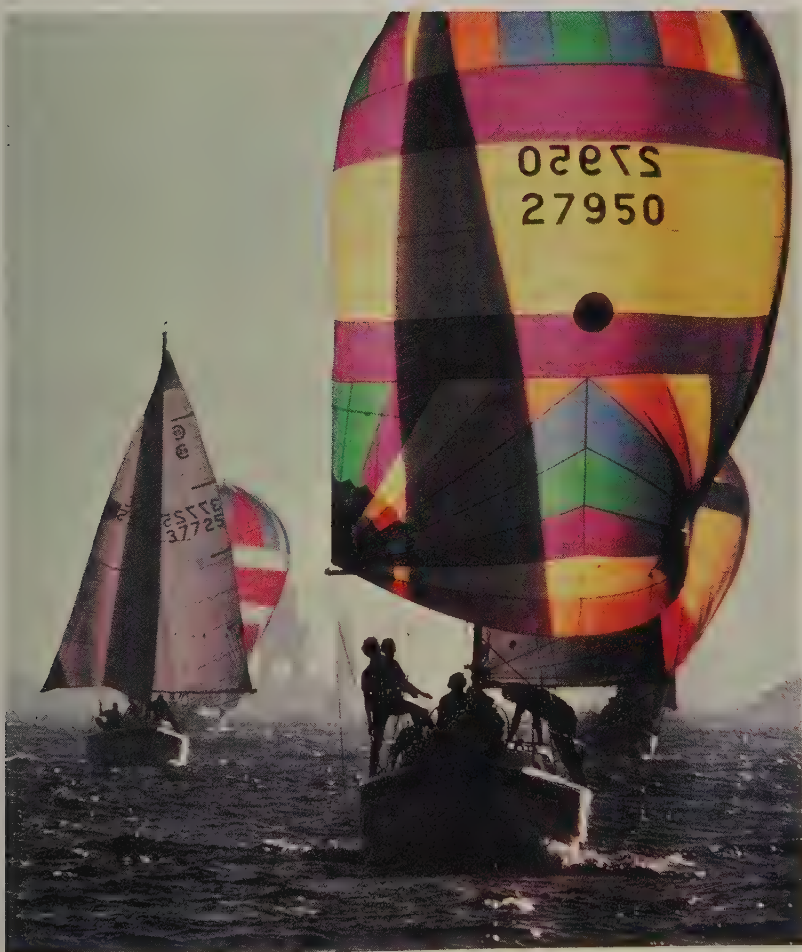


Figure 5-15. The wind cannot be seen, but its presence is revealed by the smallest blade of grass. How is the wind's presence revealed in this picture

How thick is the atmosphere, the outermost layer of the earth?

The earth, you may recall, is made up of several layers. The outermost layer is made up of invisible gases and is over 100 km thick. This layer of gases, which is called the atmosphere, is very fluid. Within the atmosphere, masses of air change shape and flow from one place to another.

Has the atmosphere ever flowed over you? Certainly. Every time you feel the wind blowing, it is really a mass of fluid air that is flowing past you as it spreads out along the surface of the earth.

In this section, you will learn the answers to various questions about the wind. What, for example, causes the winds to blow? What can a person tell about the wind by reading a weather map? And how are winds named? Does a westerly wind blow *from* the west or *toward* the west?

Convection currents and wind belts

Library research

Find out how the earth's wind belts affected navigation in the days of sailing vessels. Which areas of the ocean were particularly troublesome to navigators? for what reason(s)?

There are two general types of winds, local winds and prevailing winds. The winds that you are most familiar with are local winds. **Local winds** may blow from any direction. **Prevailing winds,** on the other hand, almost always travel longer distances and blow from the same direction. Prevailing winds are part of much larger patterns of air circulation. These general patterns of air circulation are called **wind belts.** Wind belts circle the earth and play a very important role in determining climate and weather. (Figure 5-17 on page 253 shows the earth's wind belts, which are caused by the earth's rotation.)

Watch a television weather forecast for several days in a row. Each day, you will note that weather conditions change. Temperatures rise and fall. Rain comes, skies become cloudy, or the sky clears. But if you live in the continental United States, one thing does not change. The weather conditions that the weather forecaster describes come to your area from the west. They may come from the southwest, from due west, or from the northwest. But almost always, weather conditions over the continental United States come from some westerly direction. They generally move across the continent from the west to the east. This happens because, for the most part, the continental United States lies in the wind belt of **prevailing westerlies.**

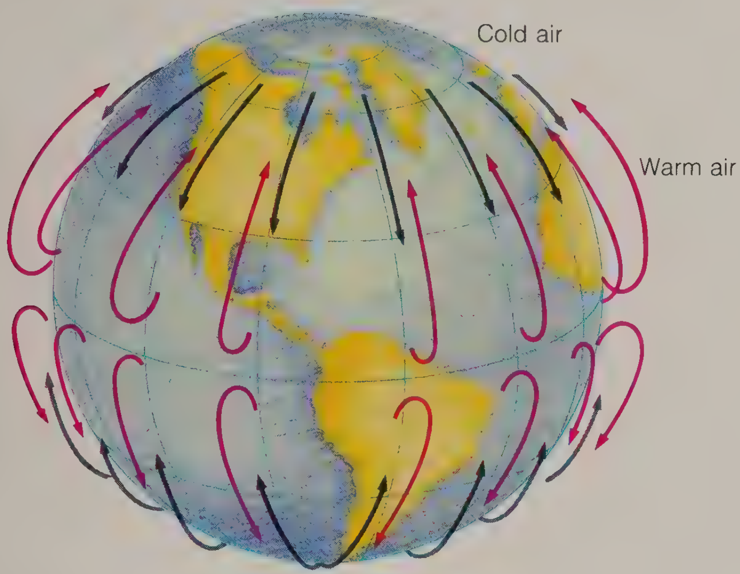


Figure 5-16. If the earth did not rotate, the earth's air would circulate in a generally north-south direction. What causes air to sink near the poles? What causes air to be forced upward near the equator?

(Note that westerly winds blow from the west. Winds are named for the direction from which they blow.)

Do westerly winds blow from the west or toward the west?

Two factors affect the direction of the prevailing winds in wind belts: 1) unequal heating of the earth's surface, and 2) the earth's rotation. Figure 5-16 shows what the pattern of air circulation on the earth would be if the earth did not rotate on its axis and if all the surface was made of the same substance (water, or rock or soil, etc.). In the Northern Hemisphere, cooled air near the North Pole would sink and flow south along the surface toward the equator. Heated air near the equator, where energy from the sun is strongest, would be forced upward by the cooler, denser air moving in underneath. This warmer, less dense air would then flow north toward the North Pole, above the cooler air that is moving south. A convection current would form from this moving air. And the flow would be in a north-south direction.

In the Southern Hemisphere, the general direction would still be north-south. But the directions between the South Pole and the equator would be reversed. Air cooled near the South Pole would move north to the equator. Air warmed near the equator would move south to the South Pole.

On a non-rotating earth, in what direction would cool air flow?

But as you may recall from Chapter 3, the earth's rotation causes what is known as the Coriolis effect. Because of the Coriolis effect, air-borne objects in the Northern Hemisphere seem to be deflected toward their right. And air-borne objects in the Southern Hemisphere seem to be deflected toward their left. To illustrate this, you might think of a rocket fired from the North Pole. If the rocket were aimed at New York when it was

Activity Forming Convection Currents

Materials

- 1000-mL heatproof beaker
- water
- wire gauze
- tripod stand
- Bunsen burner
- spoon, tweezers, or tongue depressor
- potassium permanganate
- clear plastic or glass container, shoebox size (aquarium or refrigerator container will be fine)
- ice cubes

Step 7

Purpose

To trace the movement of a convection current in a fluid.

What to Do

1. Fill the heatproof beaker about 3/4 full of water.
2. Place the beaker on the wire gauze on the stand. Let the water sit about ten minutes. Any moving currents that resulted from pouring it will stop.
3. Place the burner near one side of the beaker. Using tweezers, spoon, or tongue depressor, drop a few crystals of the potassium permanganate into the water. Drop them at the side near the burner.
   SAFETY NOTE: *Do not touch the crystals of potassium permanganate with your bare skin. Wear safety goggles.*
4. Turn on the burner and observe what happens. Then turn off the burner.
5. Next, fill the clear container 3/4 full of water. Allow it to sit for ten minutes for the water to settle.
6. Using the tweezers, spoon, or tongue depressor, drop a few crystals of potassium permanganate into the water near one end of the container.
7. Carefully add a few ice cubes to the water at the end away from the crystals. Try not to stir up the water. Observe what happens.

Questions

1. Make a simple drawing of the path that the dye follows in the heated water.
2. Sketch the path the dye follows in the water once the ice cubes are added.
3. How did the potassium permanganate dye travel in the water?
4. What does the path of the dye through the water show?

Conclusion

How does this model relate to the circulation of air in the atmosphere?

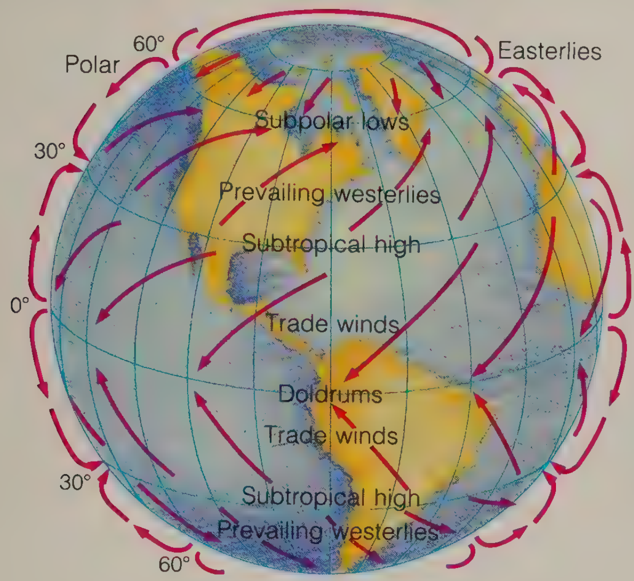


Figure 5-17. Because of the earth's rotation, the earth's air currents are deflected from a generally north-south direction. Several belts of prevailing winds are formed. What happens to the air at 30° North latitude?

fired, it would land somewhere around Chicago. Figure 5-17 shows what happens to the earth's air circulation because of the Coriolis effect. Instead of a large north-south convection current forming, several smaller currents are formed.

In Figure 5-17, you will notice that there are several zones where air is sinking or where air is being forced upward. The places where air is sinking and spreading out are called diverging zones. The places where air is coming together and is being pushed upward are called converging zones. In the Northern Hemisphere, there are diverging zones of air near the North Pole and near 30° North latitude. Converging zones are found near the equator and near 60° North latitude.

In Figure 5-17, you will also notice that some of the diverging air at 30° North latitude heads back toward the North Pole and some heads toward the equator. Above 30° North latitude, the prevailing winds are from the west to the east after the apparent deflection caused by the Coriolis effect. As mentioned earlier, these prevailing winds are called westerlies because they come from a westerly direction. Between 30° North latitude and the equator, the prevailing winds flow from the northeast to the southwest. Because they flow from the northeast, they are called the northeast trade winds.

What are the prevailing winds between 30° North latitude and the equator?

Check yourself

1. How do prevailing winds differ from local winds?
2. Explain how unequal heating and the earth's rotation affect the direction of prevailing winds in wind belts.

Specific heat and convection currents

Convection currents can form because different parts of the earth receive unequal amounts of the sun's energy. Convection currents can also form because different materials on the earth's surface absorb heat differently. At the beach on a hot summer day, you often feel a cool breeze blowing in, or flowing in, from over the water. Also, if you were in a boat out in the water, the air would be cooler than it is on the beach. These things happen because land temperatures change faster than water temperatures.

At the beach, the same amount of sunlight is shining on both the sand and the water. The surface sand becomes so hot that it burns your feet. The surface water remains cool. This indicates that it takes more energy to warm the water than it does to warm the sand. Water has what is called a higher specific heat than sand has. **Specific heat** is the amount of energy needed to raise 1 g of a substance 1°C. Water, in fact, has the highest specific heat of any common natural substance. That means that water needs to absorb a greater amount of energy before its temperature will rise.

Are sand and water warmed equally by the same amount of energy?

As shown in Figure 5-18, the difference in specific heat between land materials and water causes convection currents to form along coastal areas. During the day, the surface of the water is cooler than the surface of the land. The air over the water cools, sinks, and flows toward the land. The air over the land is hotter and less dense than the cooler air pushing in from the sea. The warm air over the land is forced upward by the cooler, denser air. A sea breeze forms, flowing from the sea to the land. This breeze is called an **onshore breeze** because it blows onto the shore from out over the sea. Onshore breezes can blow inland for many kilometers.

At night, just the opposite happens. Because the land materials contain less heat than water does when both materials are at the same temperature, land materials cool off faster than water. Also, temperature differences between land materials and water are affected because the different surfaces reflect, absorb, and radiate energy in differing amounts.

Why do land materials cool off faster than water?

At night, therefore, land temperatures become cooler than the temperature of the surface of the water. A convection cur-

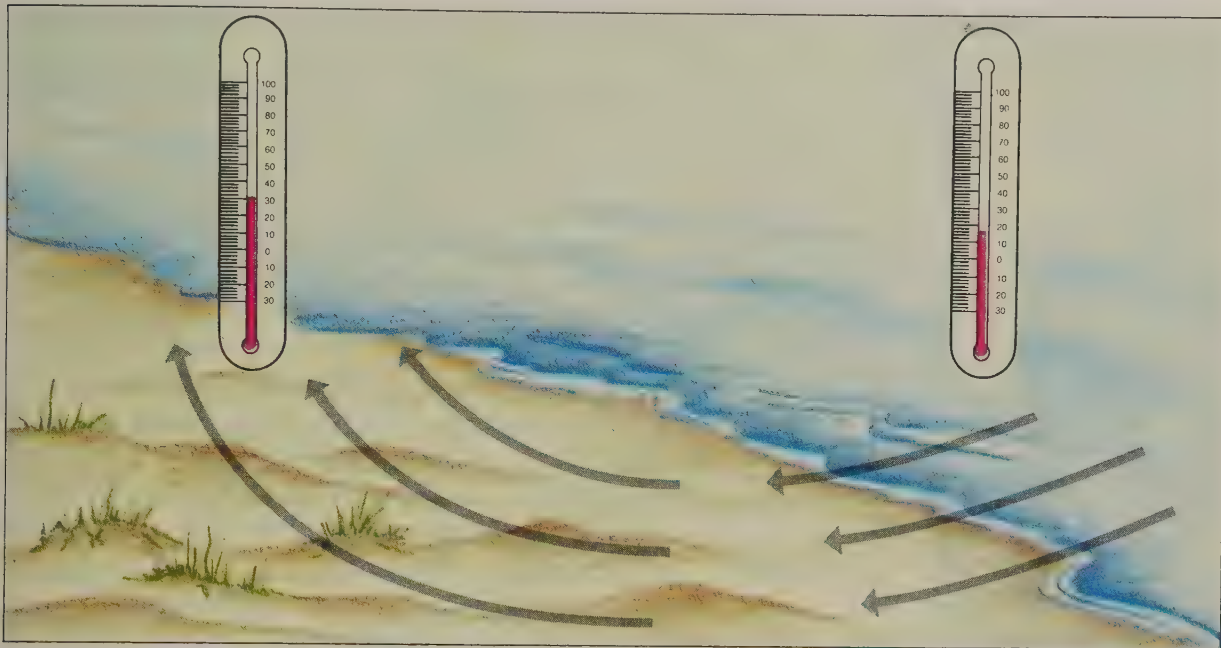


Figure 5-18. On a summer day, the sand gets hotter than the water. How can this cause a cooling sea breeze to blow in off the water?

rent forms, but it flows in the opposite direction at night. Air is now cooled over the land. This cooler, denser air sinks and spreads out over the water. This time a land breeze forms, flowing from the land to the sea. This breeze is called an **offshore breeze** because it blows off or away from the shore.

Check yourself

1. How does difference in specific heat cause convection currents in coastal areas?
2. How does the direction of breezes in coastal areas change from day to night? Why does this happen?

Atmospheric pressure and winds

The gases and other materials in the atmosphere have mass. Drawn to the earth's surface by the force of gravity, the atmosphere exerts pressure against the surface of the earth. This pressure, which is called **atmospheric pressure,** varies according to the density of the air. Denser air, which has a greater mass per unit volume, exerts greater pressure against the earth's surface than does less dense air.

Dense air, which exerts greater atmospheric pressure, moves in underneath less dense air. In other words, air moves from

areas of greater atmospheric pressure to areas of lower atmospheric pressure. Winds, therefore, blow from high-pressure areas to low-pressure areas. And if the difference in pressure between the two areas increases, the wind speed also increases.

Because winds blow according to differences in atmospheric pressure, it is important to be able to measure atmospheric pressure. The basic instrument for measuring atmospheric pressure is called a **barometer.** Atmospheric pressure is also called barometric pressure.

Some barometers use a liquid. As shown in Figure 5-19, a mercury barometer uses a column of mercury to measure atmospheric pressure. **Standard atmospheric pressure** is capable of balancing a column of mercury that is 760 mm high. As atmospheric pressure decreases, it cannot balance as much matter and the column of mercury falls. As atmospheric pressure increases, the column of mercury is forced upward.

In addition to mercury barometers, there are also aneroid barometers. An aneroid barometer (see Figure 5-21) does not use a liquid. Instead, it uses a sealed metal container from which nearly all the air has been removed. Changes in atmospheric pressure cause the sides of the container to move in or out. As the sides move, a pointer also moves, indicating the changes in atmospheric pressure.

An aneroid barometer can be hooked up to a revolving drum with paper on it. The pointer would be equipped with a pen point. The drum keeps a continuous record of all changes in atmospheric pressure registered by the barometer. This instrument, which is shown in Figure 5-22, is called a barograph.

"Standard atmospheric pressure," or barometric pressure, can be expressed in a variety of values. It can, for example, be expressed as "one atmosphere." In terms of a column of mercury, one atmosphere equals 760 mm (or 29.92 in.) of mercury.

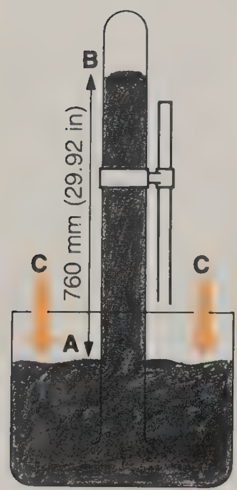


Figure 5-19. The height of the mercury column (from A to B) is determined by the atmospheric pressure (C) on the mercury.

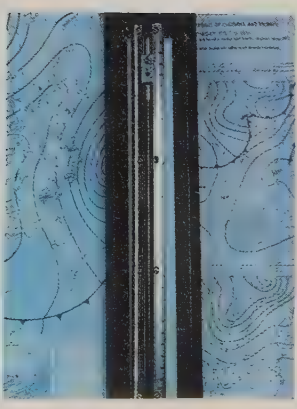


Figure 5-20. a mercury barometer

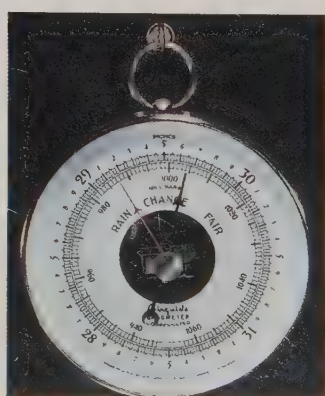


Figure 5-21. an aneroid barometer

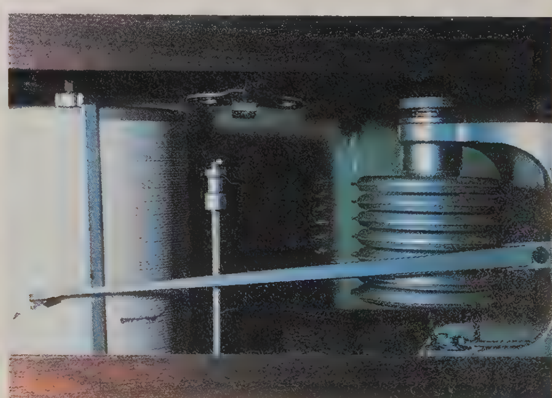


Figure 5-22. a barograph

Standard atmospheric pressure can also be expressed in terms of a column of water, which is much less dense than mercury. In terms of a column of water, one atmosphere equals 1033.3 cm (or 33.9 feet) of water. Standard atmospheric pressure can also be expressed as 1013.25 millibars. **Millibars** are the unit of pressure measurement most commonly found on weather maps.

Check yourself

1. How does atmospheric pressure affect wind?
2. Explain how a mercury barometer works.

The density of the atmosphere

Standard atmospheric pressure is measured at sea level and at 0°C. That is because the density of the earth's atmosphere is affected by three factors: by moisture (water vapor), by height above sea level (elevation), and, as you have already seen, by temperature.

The amount of moisture in the air affects the density of the atmosphere. As the amount of moisture in the air increases, the air becomes less dense because molecules of water have less mass than molecules of other gases in the air. Figure 5-23 shows different layers of the earth's atmosphere. Just about all the moisture in the atmosphere is found within the **troposphere,** which extends to about 16 km above sea level. (The troposphere is also the level of the atmosphere in which all of the earth's weather is found.)

Above the troposphere is the *stratosphere,* up to 50 km above sea level. The stratosphere contains the *ozone layer,* with ozone O_3 molecules. These filter dangerous rays from the sun. Above this is the *mesosphere* up to 80 km and the *thermosphere,* an even thinner layer in the atmosphere which goes beyond 100 km above sea level. Air is extremely thin in these upper layers. However, most speeding *meteors* burn up when they enter the atmosphere here. The friction of the speeding rock against the thin air molecules produces tremendous heat.

Height above sea level affects the density of the atmosphere. Starting from the earth's surface, the atmosphere becomes less and less dense as distance above the earth's surface increases. If you were to climb a mountain a few kilometers high, you

Library research

Prepare a report that describes the development of a scientific instrument connected with energy and the atmosphere. It can be an instrument used in the past or in the present. Include dates and the names of the inventors and developers.

Why is standard atmospheric pressure measured at sea level and at 0°C?

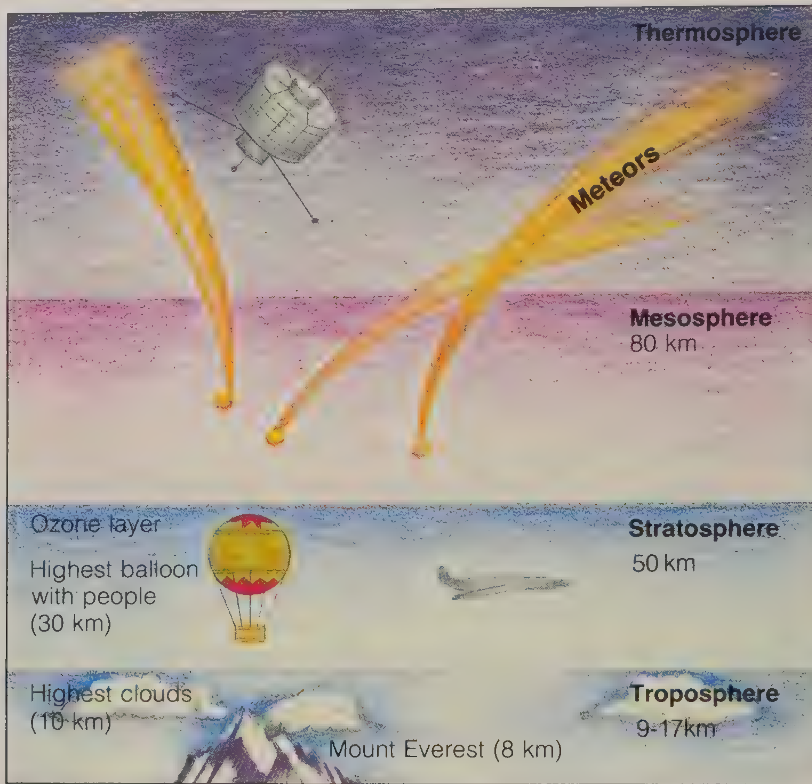


Figure 5-23. All of the earth's weather and just about all of the moisture in the atmosphere are found in the same layer of the atmosphere. What is the name of that layer?

would find that you get winded more easily. The air at that altitude is thinner. With each breath, you draw in less oxygen than you do when you breathe at sea level.

About 90% of all the gas in the atmosphere is found within a few kilometers of the earth's surface. In high-flying airplanes, machines must supply air for people to breathe. The air outside the plane is too thin to support life. And beyond 100 km, very little atmosphere remains. People traveling in space must bring their own air supply with them.

In high-flying airplanes, why must machines supply air for people to breathe?

Variations in the density of the atmosphere cause variations in atmospheric pressure. Variations in atmospheric pressure play a major role in determining wind speed and direction. And wind speed and direction play a major role in determining local weather patterns on earth.

Check yourself

1. How does amount of moisture affect the density of the atmosphere? Why?
2. How does height above sea level affect the density of the atmosphere?

Reading an atmospheric pressure map

As mentioned earlier, variations in elevation of features on the earth's surface can be shown on a topographic map. Variations in atmospheric pressure from one location to another can be shown on a pressure map. Atmospheric pressure measurements are made at different locations. These readings are sent to central recording stations. At the stations, the readings are plotted on a map. This map, which can be called a **pressure map,** provides a picture of the pressure pattern in a state or country.

To make it easier to see the pressure pattern, locations that have the same atmospheric pressure are connected by means of a line called an **isobar.** A topographic map uses contour lines to connect points that have the same elevation. A pressure map uses isobars to connect points that have the same atmospheric pressure.

How are contour lines and isobars similar?

Figure 5-24 shows a pressure map with isobars. On this map, the lines form a circular pattern. The pressure decreases toward the center of the pattern. This pattern is called a low-pressure area. The letter L or the word Low is used to label a **low-pressure center,** which is the center of a low-pressure area. Since atmospheric pressure is lowest at the center of a low-pressure area, winds will tend to blow in toward and slightly to either the right or left of a low-pressure center.

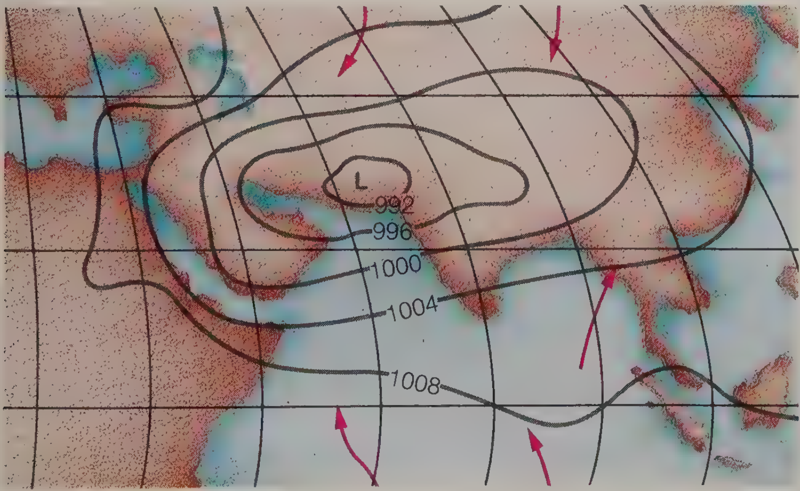


Figure 5–24. Isobars connect locations that have the same atmospheric pressure. Does the atmospheric pressure increase or decrease toward the center of a low-pressure area (indicated on a map by the letter L or the word Low)?

Activity Comparing Differences in Specific Heat

Materials

sand or soil, at room temperature
water, at room temperature
2 plastic containers
light source
stand for light source

Purpose

To compare the specific heats of water and sand or soil.

What to Do

1. Pour a measured amount of sand into one container. Pour an equal amount of water into the other container.
2. Insert one thermometer into the sand so that the bulb is just below the surface. Suspend the other thermometer on a string so that its bulb is just below the surface of the water.
3. The sand and the water should be about the same temperature. If they are not, wait for a while until they are.
4. Prepare a chart that begins like the one shown. Note that some of the readings are with the light source on and others with the light source off.
5. Attach the light souce to the stand and position the stand so that the light shines equally on both containers. Do not turn the light source on yet.
6. Take your first temperature reading for the sand and water. Record these temperatures as reading number 1 on your chart. Then turn the light source on.
7. Take temperature readings of the materials each minute until you reach reading number 10. Record each reading on your chart.
8. After reading number 10, turn off the light source. Continue to take temperature readings with the light source off every minute until you reach reading number 20.

Questions

1. In which material did the temperature rise more when the light source was on?
2. In which material did the temperature drop more when the light source was off?
3. From the data on your chart, which material has the higher specific heat? Explain.

Conclusion

Which material holds a more steady temperature? Do the materials receive the same amount of energy? What reasons can you give for your answer? Review page 254.

Temperature with Light Source On		
Reading	Sand	Water
1		
2		
3		
4		

Temperature with Light Source Off		
Reading	Sand	Water
11		
12		
13		
14		

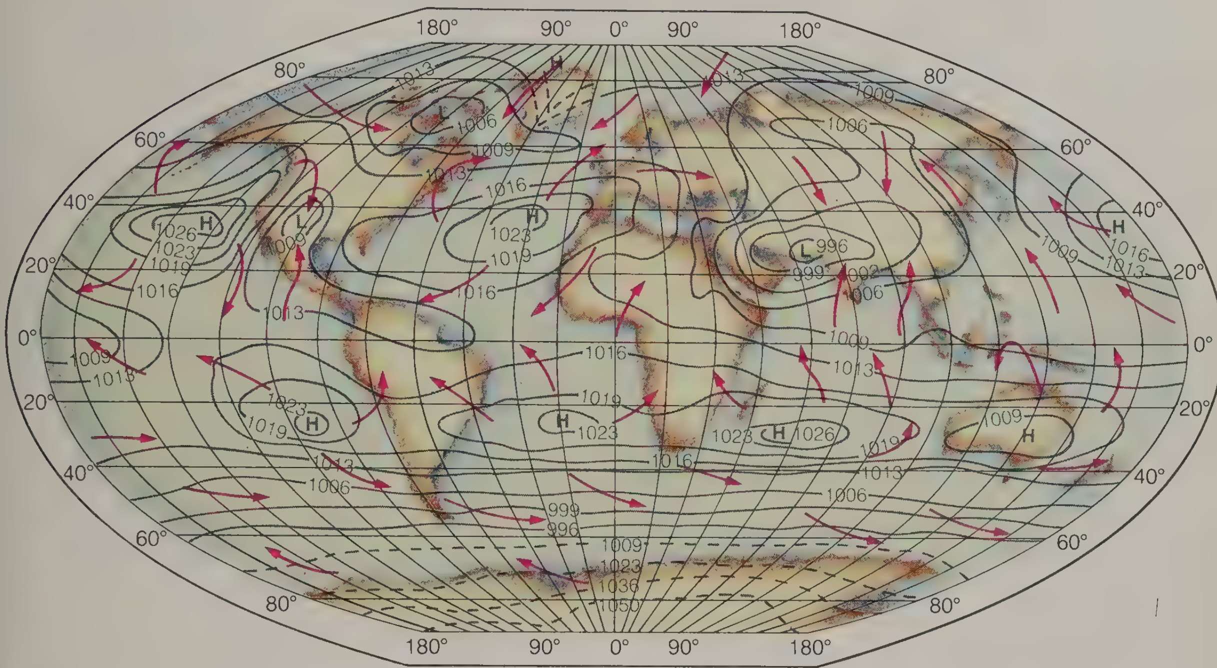


Figure 5-25. In the Northern Hemisphere, in what direction do winds blow away from a high-pressure center?

For a **high-pressure center,** which is the center of a high-pressure area, the pattern is reversed. The pressure increases toward the center. Winds will therefore tend to blow out from a high-pressure center. The letter H or the word High is used to indicate a high-pressure center.

Figure 5-25 shows a typical pressure map for July. On the map, you will notice several high-pressure and low-pressure centers. Arrows indicate the pattern of wind movement. Notice that the winds do not blow straight into a low-pressure area or straight out of a high-pressure area. The winds are deflected by the Coriolis effect that is caused by the earth's rotation.

From the map in Figure 5-25, you can draw several conclusions about winds. 1) Winds blow from regions of high pressure to regions of low pressure. 2) In the Northern Hemisphere, winds blow away from high-pressure centers in a clockwise direction. 3) In the Northern Hemisphere, winds blow toward a low-pressure center in a counterclockwise direction.

Check yourself

1. Describe a pressure map.
2. How do high-pressure areas, low-pressure areas, and the Coriolis effect influence the direction of winds that are found in the Northern Hemisphere?

Section 2 Review Chapter 5

Check Your Vocabulary

atmospheric pressure	onshore breeze
barometer	pressure map
high-pressure center	prevailing westerlies
isobar	prevailing winds
local winds	specific heat
low-pressure center	standard atmospheric pressure
millibar	troposphere
offshore breeze	wind belts

Match each term above with the numbered phrase that best describes it.

1. Winds specific to a local area
2. The unit of atmospheric pressure measurement commonly found on weather maps
3. The layer of the earth's atmosphere closest to the earth's surface
4. A map that indicates atmospheric pressure patterns for an area of the earth's surface
5. A line that connects locations having the same atmospheric pressure
6. The center of an area of low atmospheric pressure
7. The center of an area of high atmospheric pressure
8. A breeze that blows away from the shore and out over the sea
9. The pressure the atmosphere exerts against the surface of the earth
10. The basic instrument for measuring atmospheric pressure
11. Atmospheric pressure at sea level and 0°C
12. Winds that are part of much larger patterns of air circulation than local winds
13. General patterns of air circulation that circle the earth; includes prevailing winds
14. Winds that blow from a westerly direction
15. The amount of energy needed to raise 1 g of a substance 1°C
16. A breeze that blows onto the shore

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Places around the earth where cool air sinks and spreads out along the earth's surface are called _?_.
   a) prevailing westerlies
   b) converging zones
   c) local winds
   d) diverging zones
2. _?_ has the highest specific heat of any common natural substance.
   a) Rock c) Water
   b) Sand d) Air
3. Molecules of water have _?_ mass than molecules of other gases in the air.
   a) less c) the same
   b) slightly more d) much more

Check Your Understanding

1. There would be no wind if the atmosphere were not fluid. Explain.
2. Explain the relationship between prevailing westerlies and the Coriolis effect.
3. How does specific heat affect air temperatures?
4. Explain the relationship between wind and atmospheric pressure.
5. As you climb a mountain, what two atmospheric changes can you expect? How will you notice these changes?

Moisture and the Atmosphere Section 3

Section 3 of Chapter 5 is divided into six parts:

Energy and the states of water

Water vapor in the atmosphere

When does condensation occur?

Condensation near the earth's surface

Condensation in the atmosphere

Precipitation

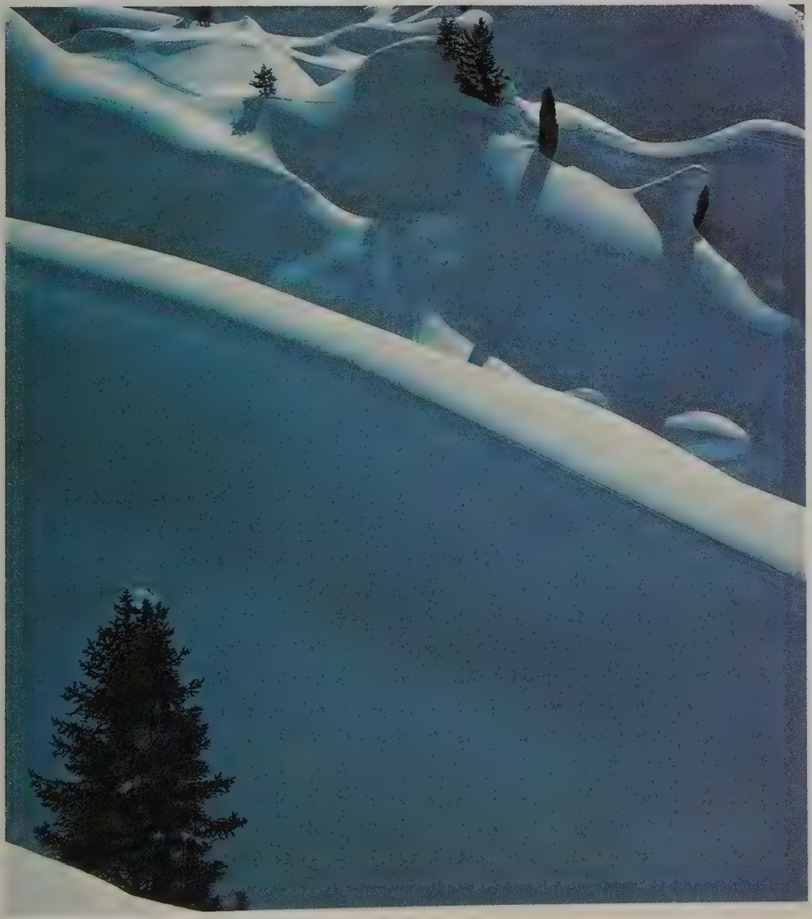
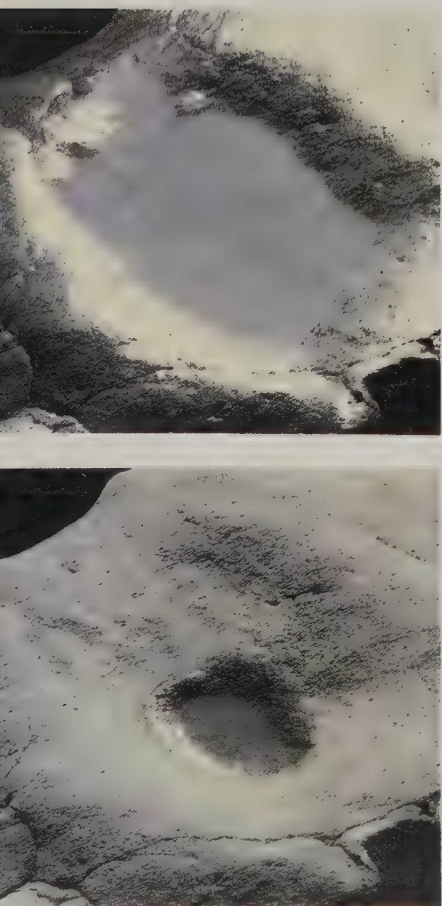


Figure 5-26. In this picture, you see the sun shining on snow in the French Alps. You know that the sun can melt snow. In this section, you will learn how the sun causes snow.

Energy from the sun provides light and warmth on the earth. Energy from the sun causes the winds that blow across the face of the earth. Energy from the sun also causes the rain that falls upon the dry land. How can the sun be the cause of both sunshine and rain? How can the sun be the cause of even the snowstorms and hailstorms that occur on the earth?

Energy and the states of water

Figure 5-27. Here are two pictures of the same puddle. The puddle at the bottom shows how evaporation caused the puddle to become smaller.



Water is a compound that is made up of the elements hydrogen and oxygen. Its chemical formula, H_2O, indicates that each molecule of water is made up of one atom of oxygen and two atoms of hydrogen.

On the earth, water can be found in any of the three physical states of matter. That means that water can be found as a liquid, as a solid, and as a gas. **Water vapor** is the name commonly used for water as a gas. Whether water is found as a liquid, solid, or vapor at a particular location depends largely on heat energy.

You are familiar with the physical properties of water as a liquid and water as a solid (ice). But what is water vapor like? Water vapor cannot be seen or tasted or smelled or felt. Water vapor is an invisible gas. Some water vapor is present in all the air that is closest to the earth's surface.

Not only does water exist as a liquid or a solid or a vapor, but water can also be easily changed from one state to another. Once again, it depends on heat energy.

The changing of a substance from a liquid into a vapor or gas is called **evaporation.** When water changes from a liquid to a vapor, it must take in energy. The amount of heat needed for 1 g of a substance to become a vapor is called its **heat of vaporization.** When liquid water is able to take in its heat of vaporization from its surroundings, the liquid water changes to water vapor. Because of the needed heat of vaporization, water vapor contains much more energy than liquid water.

The changing of a vapor into a liquid is called **condensation.** The word *condensation* comes from Latin words that mean "to make very dense." Liquid water is about one thousand times denser than water vapor.

Figure 5-28. When liquid water freezes, does it give off energy or does it gain energy?

When water changes from a vapor to a liquid, it gives off energy to its surroundings. It loses the same amount of heat that it gained through its heat of vaporization.

What do you suppose happens when ice, which is water in its solid state, melts? Do you think it takes in energy or gives off energy? When ice melts, water changes from a solid to a liquid. For this to happen, solid water must take in energy. The amount of heat needed for 1 g of a solid substance to melt and become a liquid is called its **heat of fusion.** When ice is able to take in its heat of fusion from its surroundings, the solid water changes to a liquid.

When liquid water freezes, just the opposite happens. Freezing water gives off energy to its surroundings. When liquid water freezes, it loses the same amount of heat that it gained through its heat of fusion.

Library research

Find out how much of the earth's water supply is in the form of ice. Where is this ice located? Why is ice found in those regions?

Check yourself

1. Water vapor contains much more energy than liquid water. Explain.
2. In terms of energy transfer, what happens when ice melts?

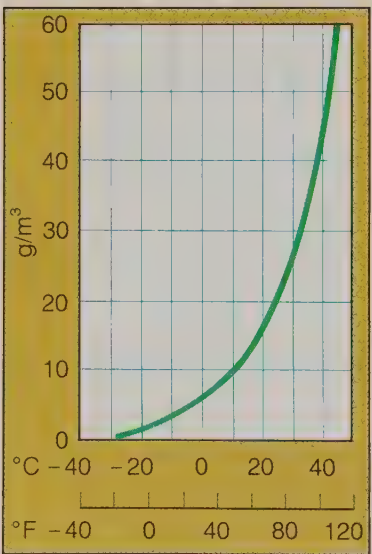
Water vapor in the atmosphere

Water vapor makes up a very small but very important part of the earth's atmosphere. In very moist air, only 3% of the total volume of air is water vapor. In drier air, the amount of water vapor present is less. But even in very dry areas, there is always some moisture left in the atmosphere.

Where does this moisture come from? And how does it get into the atmosphere? The water in the atmosphere evaporated from liquid water on the earth's surface. Heat energy from the sun provided the needed heat of vaporization so that liquid water could change into vapor.

Water is always evaporating from the surface of lakes, rivers, and oceans. Water evaporates from puddles. Water evaporates from the moisture in the ground. Water even evaporates from the surface of a person's skin. From the smallest puddles and drops of perspiration to the largest oceans, water is evaporating into the atmosphere day after day. Plants also release water vapor into the atmosphere. The water vapor is released through tiny openings on the undersides of the plants' leaves. This process, called transpiration, is described on page 347.

Figure 5-29. The maximum amount of water vapor that air can hold depends on the temperature of the air. At 40°C, how many grams of water vapor can a cubic meter of air hold?



There is a limit to the amount of moisture that air can hold. When the air is holding all the moisture it can, we say that the air is saturated. **Saturated air** is air that can hold no more moisture. Once the air becomes saturated, it must return any extra moisture to the earth's atmosphere by condensation.

The amount of water vapor the air can hold depends upon the air temperature. At higher temperatures, the same volume of air can hold more water vapor. As shown in Figure 5-29, a cubic meter of air at 10°C can hold 10 g of water vapor. At 40°C, the same volume of air can hold about 50 g of water vapor.

Perhaps you have heard of the terms *humidity* and *relative humidity*. They have to do with the amount of moisture in the air. **Humidity** is the amount of moisture that is in the air. **Relative humidity** is a comparison between the amount of moisture in the air and the amount that the air can hold. Relative humidity is expressed as a percentage. A relative humidity of 50% means that the air contains half of the total amount of

moisture that it can hold at that temperature. When the air is saturated, its relative humidity is 100%.

What is a sling psychrometer used for?

One instrument that is often used to measure the amount of moisture in the air is the **sling psychrometer.** It consists of two thermometers fastened to a base. A wet cotton wick is attached to one of the thermometers. The psychrometer is swung in a circular motion. The thermometer without the wick measures the dry bulb temperature, which is the temperature of the air. Twirling the psychrometer does not affect the dry bulb reading. If the air temperature is 30°C, then the dry-bulb reading remains at 30°C when the psychrometer is twirled.

Figure 5-30. A sling psychrometer uses two thermometers to measure the relative humidity of the air.

The temperature of the other thermometer, the wet-bulb thermometer, drops when the psychrometer is twirled. As water evaporates from the wick, the temperature of the wet-bulb

Activity Finding the Relative Humidity

Materials

sling psychrometer
water at about room temperature
clock or watch that indicates seconds
relative humidity table on page 600 of the Appendix

Purpose

To use a sling psychrometer to find the relative humidity of the air.

What to Do

1. Wet the wick of the wet-bulb thermometer of your sling psychrometer. Use water that is at or near air temperature. Record the temperatures of both the wet-bulb and dry-bulb thermometers.
2. Before twirling the psychrometer, make sure no person or object is near enough to get hit by the moving psychrometer. Then twirl the psychrometer for about 15 seconds. Record the temperature of both thermometers.
3. Twirl the psychrometer for another 15 seconds. Again record the temperatures.
4. Repeat this process until the wet-bulb temperature stops dropping. (The dry-bulb temperature should remain the same.)
5. Subtract the final wet-bulb temperature from the dry-bulb temperature to calculate the wet-bulb depression.
6. Use the relative humidity table on page 600 of the Appendix to find the relative humidity. Locate your calculated wet-bulb depression along the top of the relative humidity table. Then locate your closest dry-bulb temperature down the left side of the table. Reading across from the dry-bulb temperature and down from the wet-bulb temperature, find where the two lines intersect. You will then see the relative humidity for your temperature readings. For example, if your wet-bulb depression is 5°C and your dry-bulb temperature is about 20°C, then the relative humidity is about 59%.

Step 2

Question

What relative humidity did you find from your measurements and calculations?

Conclusion

Look again at the relative humidity table in the Appendix. At 20°C and a 5°C wet-bulb depression, the relative humidity is 59%. At 20°C dry-bulb temperature and 1° wet-bulb depression, the relative humidity is 91%. At 20°C dry-bulb temperature and 10° wet-bulb depression, the relative humidity is 24%. The lower the wet-bulb depression is at any given temperature, the higher the relative humidity is. Can you explain this pattern? Review the discussion of evaporation on page 264.

thermometer drops because water that evaporates is taking heat energy from its surroundings. Also, the amount of moisture in the air affects the rate of evaporation. When there is less moisture in the air, more water evaporates from the wick. This causes a greater drop in the wet-bulb temperature.

The difference between the dry-bulb temperature and the wet-bulb temperature is a relative measure of the amount of moisture in the air. On a very humid day, the wet-bulb temperature may drop only one or two degrees. If, however, the air is dry, the wet-bulb temperature may drop ten degrees or more.

Check yourself

1. If the relative humidity is 50%, what does that say about the moisture content of the air?
2. Explain how a sling psychrometer indicates relative humidity.

When does condensation occur?

As mentioned already, warmer air can hold more water vapor than cooler air. Suppose the air temperature were 30°C and the air were saturated. What do you think would happen when the temperature of that saturated air starts to drop?

First, we must consider what we mean when we say that the air is saturated. We mean that the air contains all the water vapor it can hold at that temperature. Its relative humidity is 100%. When air is at its **saturation temperature,** or dew-point temperature, there is a balance between the number of molecules of water vapor entering and leaving the air. For every molecule of water vapor that enters saturated air through evaporation, one must leave. There is just no more room for extra molecules of water vapor in that mass of air as long as it stays at the same temperature.

What is the relative humidity of saturated air?

What happens when air cools below its saturation temperature? As air cools, it can hold less and less water vapor. As the temperature of the air drops below its saturation temperature, more and more water vapor must leave the air. How does this

Careers Weather Forecaster / Weather Technician

In order to predict the weather in advance, a weather forecaster analyzes data from a variety of sources.

Weather Forecaster

Weather forecasters predict future weather. They work for television and radio stations, airlines, utility companies, the armed forces, and government agencies.

In order to predict the weather for more than a few hours ahead, forecasters must have weather data for a wide area. They get this information from National Weather Service maps, which indicate such data as wind speed, temperature, and humidity for locations all over the world. Forecasters are also able to use pictures of weather systems obtained from weather satellites in orbit around the earth.

Forecasters compare past and current maps to find out how weather systems are moving. They use their map analysis plus their knowledge of local weather conditions and patterns to prepare forecasts for their area.

If you are interested in becoming a weather forecaster, take math and science courses in high school. Since weather forecasters are meteorologists, you will study meteorology in college.

If you are one for immediate action, you can start with today's weather maps and conditions. Keep records. Look for patterns. Then try your hand at some short-range forecasting!

Weather technicians operate and maintain electronic equipment used for gathering weather data.

Weather Technician

Weather technicians operate and maintain weather instruments such as anemometers, barometers, and psychrometers. They also operate and maintain electronic equipment such as weather data processors.

Weather technicians measure weather conditions, plot weather data on charts and diagrams, and maintain weather data files. Some weather technicians prepare forecasts.

As a weather technician, you will be able to assist a meteorologist in a variety of ways. You might be a weather observer, a weather chart preparer, or a weather clerk.

Training for a weather technician is available at vocational and technical schools and through specialized training courses offered to members of the armed forces. In high school, plan to take math and science courses. And all the while, of course, keep an eye on the weather!

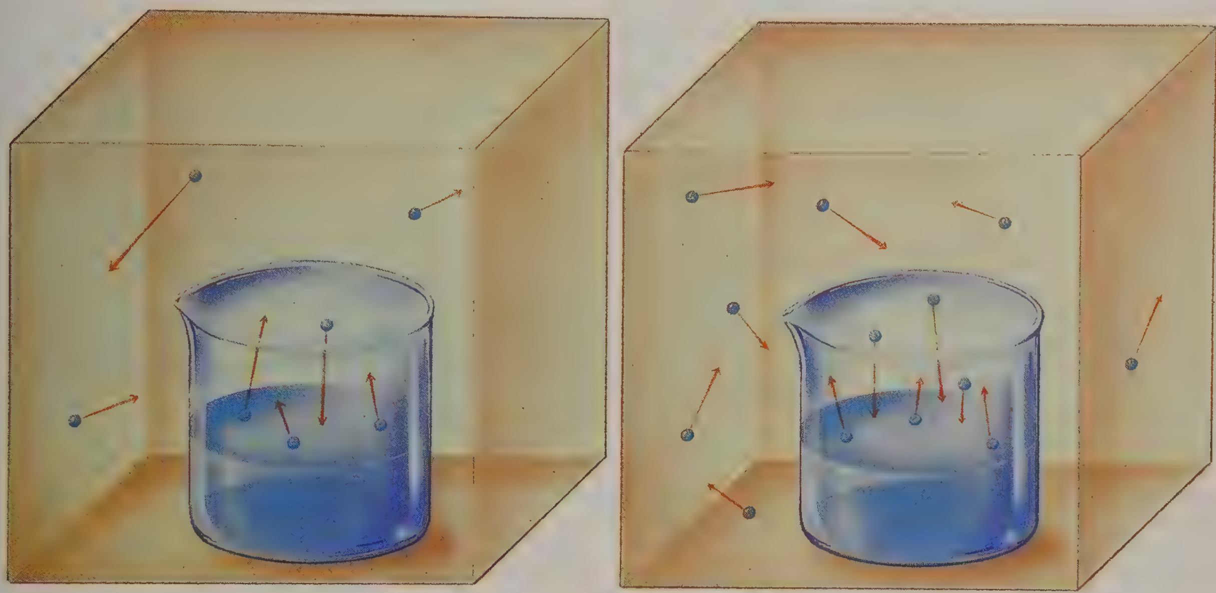


Figure 5-31. When the air is at its saturation temperature, an equal number of molecules are escaping from and returning to the surface of the water. Which picture represents air at its saturation temperature?

happen? Water vapor leaves the air by changing into droplets of water that form around tiny particles of matter in the atmosphere. These microscopic particles are called condensation nuclei. Salt provides many of these particles to the atmosphere.

For this changing of water vapor into liquid water, which is called condensation, three conditions are necessary. 1) The air must be cooled to its saturation temperature. 2) There must be moisture available in the form of invisible water vapor. 3) There must be a surface on which water vapor can condense. Since tiny particles or dust and other solid matter are present throughout the atmosphere, condensation readily occurs whenever air reaches its saturation temperature.

You have probably seen condensation occur on the outside of a can, glass, or pitcher containing an ice-cold liquid. Drops of moisture form on the outside of the container. The cold surface of the container cools the air near the surface of the container. The air near the surface of the container is cooled to its saturation temperature. The extra water vapor condenses on the surface of the container. If you wipe the moisture away, more will form. As long as the air near the container is being

Why do drops of moisture form on the outside of a container of cold liquid?

Activity Finding the Dew-Point Temperature

Materials

drinking glass or shiny can
water at room temperature
warm water
thermometer
ice chips or cube
sling psychrometer

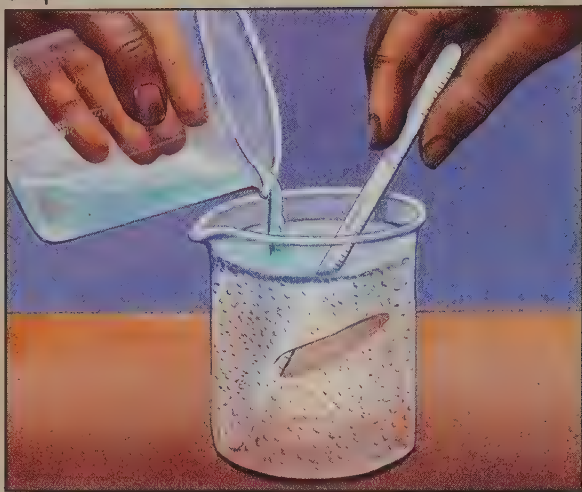
Purpose

To find the dew-point temperature of the air you are breathing.

What to Do

1. Put some water in a can or glass. (The water should be at about room temperature.)
2. Slowly add ice chips to the water. Stir the water with a thermometer until drops of moisture first begin to form below the waterline on the outside of the container.
3. Record the water temperature as soon as you notice the slightest film of moisture begin to form on the outside of the container.
4. Remove the ice. Trace your finger across the outside of the container to make a clear path through the beads of moisture.
5. Slowly raise the temperature of the water inside the container to the point where no film forms in the freshly cleared area on the surface. Raise the temperature by slowly adding warm water to the water in the container, constantly stirring with the thermometer.
6. Record the temperature of the water when no drops of moisture form in a cleared area.
7. Calculate the temperature that is halfway between the two temperatures you recorded. It should be near the dew-point temperature of the air.
8. Repeat the cooling and warming several times, if time allows.

Step 5



9. Using a sling psychrometer and the dew-point temperature table on page 602 of the Appendix, find the actual dew-point temperature.

Questions

1. What dew-point temperature did you get using the cold-water/warm-water method?
2. If you repeated the activity several times, were your results nearly the same each time? Compare your results with those of others in the class.
3. How did the dew-point temperature you obtained from the table compare with your calculation?

Conclusion

Look at the dew-point temperature table. Read across from a dry-bulb temperature reading of 20°C. Recall from the activity on page 268 that the higher the wet-bulb depression, the lower the relative humidity. What relationship can you see between relative humidity and dew-point temperature if the dry-bulb temperature stays the same?

Figure 5-32. The outside of the pitcher on the right is covered with water droplets. Where did the moisture in the water droplets come from?

cooled enough, then water vapor from the saturated air will condense on the surface of the container.

The temperature to which air must be cooled to reach its saturation point is called its **dew-point temperature,** or saturation temperature. The dew-point temperature is the temperature at which the air contains all the water vapor it can hold. Suppose the temperature of ice water in a pitcher is 5°C and that the air temperature around the pitcher is 30°C. Suppose also that the dew-point temperature, or saturation temperature, of the air surrounding the pitcher is 20°C. This means that when the air near the surface of the pitcher is cooled to 20°C, condensation will begin. As soon as the air in contact with the outside of the pitcher reaches 20°C, water droplets will begin to form on the surface of the pitcher.

The dew-point temperature varies with the amount of water vapor present in the air. Air containing less water vapor must be cooled to a lower temperature before it becomes saturated. As the amount of water vapor in the air decreases, the dew-point temperature drops. For this reason, the dew-point temperature also indicates something about the amount of water vapor in the air. Air with a dew-point temperature of 20°C contains more water vapor than air with a dew-point temperature of 10°C. In Figure 5-32, the surface temperature of the

pitcher on the right has cooled the surrounding air below its dew-point temperature. The condensation on the outside of the container is evidence that this has occurred.

Check yourself

1. Explain why droplets of water form on the outside of a container of ice water.
2. What is the relationship between the dew-point temperature and the saturation point of air?

Condensation near the earth's surface

The part of the earth that is in night receives no energy from the sun. That part of the earth cools down. If night air near the earth's surface cools down below its saturation point, condensation will occur. Dew, frost, and fog are caused by condensation that occurs near the earth's surface.

Dew is the droplets of water that can be found on the surfaces of leaves and grass early in the morning. Dew forms because during the night the air near the earth's surface is cooled below its dew-point temperature. This happens because the earth's surface cools to a temperature below the dew-point temperature of the air. Both conditions needed for condensation are present. 1) The night or early-morning air has cooled to its saturation temperature. 2) Objects like grass and leaves provide surfaces on which the extra water vapor can condense.

Frost forms in the same way as dew. But in order for frost to form, the dew-point temperature of the air must be below 0°C, the temperature at which water freezes. When such air is cooled below its dew-point temperature, ice crystals form instead of water droplets. This produces frost rather than dew. The process of water vapor changing from a gas to a solid is called sublimation.

Dew and frost occur when water vapor condenses on objects on the earth's surface. The excess water vapor from the cooling of saturated air can also condense on tiny particles of dust and other solid matter near the earth's surface. Millions of tiny water droplets form, producing a thick fog.

Fog is really just a cloud that has formed on the earth's surface.

Most fogs form at night when the earth's surface cools and heat flows from the air to the land. Also, fogs often occur near bodies of water. As you may recall, air temperatures at night are warmer over bodies of water than over the land. That is because the land, which has a lower specific heat, cools off faster. The warm air over the water can hold more moisture than the cooler air over the land. When warm, moist air moves in over the cooler land surfaces, fog often occurs.

Figure 5-33. Fog is actually a cloud near the surface of the earth. Fog can form over land or water when the air is cooled below its dew-point temperature.

Check yourself

1. What conditions are necessary for frost to form?
2. How does fog differ from dew and frost?

Condensation in the atmosphere

Air may be cooled below its dew-point temperature by coming into contact with a cool surface. This is what happens when moisture forms on a pitcher of ice water. This is also what happens when dew, frost, and fog form during the night and early morning.

What happens to the temperature of air as it rises above the earth in a convection current?

Air is also cooled when it is lifted above the earth in convection currents. Most of the water vapor in the atmosphere is found in the troposphere, which is the zone of the atmosphere nearest the earth's surface. In the troposphere, it normally gets colder as altitude above sea level increases.

What do you think happens when warm, moist air is forced up in a convection current? Try to imagine that body of air becoming increasingly cooler as it rises above the earth's surface. At some point, that mass of air will cool below its dew point. Condensation will occur on the tiny particles of solid matter that are present in the atmosphere. If you look at the sky right now, chances are you can see some examples of this

Figure 5-34. Stratus clouds are horizontal layered clouds. What causes stratus clouds to form in layers?

Figure 5-35. Cumulus clouds, which usually form from upward-moving air, can be very large. What two factors determine the size of a cumulus cloud?

kind of condensation. They are called **clouds.**

What are the names of two general cloud types?

Almost all clouds fall into one of two general types—stratus clouds or cumulus clouds. The word *stratus* comes from the Latin word that means "to spread out." **Stratus clouds** are horizontal, layered clouds that stretch out across the sky like a blanket. Sometimes a layer of warm, moist air passes over a layer of cool air. Stratus clouds often form at the boundary where these layers meet. Where two such layers of air meet, the warm air is cooled. If the warm air is cooled below its dew point, the excess water vapor condenses to form a blanket-like layer of stratus clouds. If the layers of air are very large, the stratus clouds may extend for many kilometers across the sky.

The word *cumulus* comes from the Latin word for a heap or a pile. **Cumulus clouds** are puffy in appearance. They look like large cotton balls. Cumulus clouds usually form when warm, moist air is forced upward. As this air rises, it is cooled. If it is cooled below its dew-point temperature, condensation will occur. The size of a cumulus cloud depends on the force of the upward movement of air and the amount of moisture in the

Figure 5-36. Cirrus clouds are so thin that sunlight can shine through them. What are cirrus clouds made of?

air. The largest cumulus clouds are caused by very strong upward movements of warm, moist air. The clouds that produce heavy thunderstorms in summer are a form of cumulus clouds called cumulonimbus. Cumulonimbus clouds may extend upward for hundreds of meters.

Cirrus clouds are a third general type of cloud. The word *cirrus* comes from the Latin word for a tuft or curl of hair. **Cirrus clouds** are very wispy and feathery looking. They form only at high altitudes, about 7 km above the earth's surface. Cirrus clouds are composed of ice crystals and are so thin that sunlight can pass right through them.

Check yourself

1. What two conditions in the troposphere affect the formation of clouds?
2. How do cumulus clouds and stratus clouds differ in appearance? What causes this difference?

Precipitation

Clouds form as a mass of air is cooled below its dew-point temperature. Clouds are formed of tiny water droplets that are small enough to stay suspended in the air. But as the cooling continues, more and more water vapor condenses. The size of the cloud increases. The size of the water droplets also increases as they hit against one another and become joined together. Sometimes the drops of water become too big to remain suspended in the air. When this happens, the water falls to the earth's surface.

What happens as an air mass containing a cloud continues to cool?

Any form of water that falls to the earth from the atmosphere is called **precipitation.** The word *precipitation* comes from a Latin word that means "to throw down headfirst." Precipitation of water from the atmosphere can occur in several forms, depending on air temperature.

The most common forms of precipitation are rain and snow. **Rain** is merely drops of water that have become too large to remain in the air. A single raindrop is about one million times larger than a cloud particle. Flakes of **snow** form when the

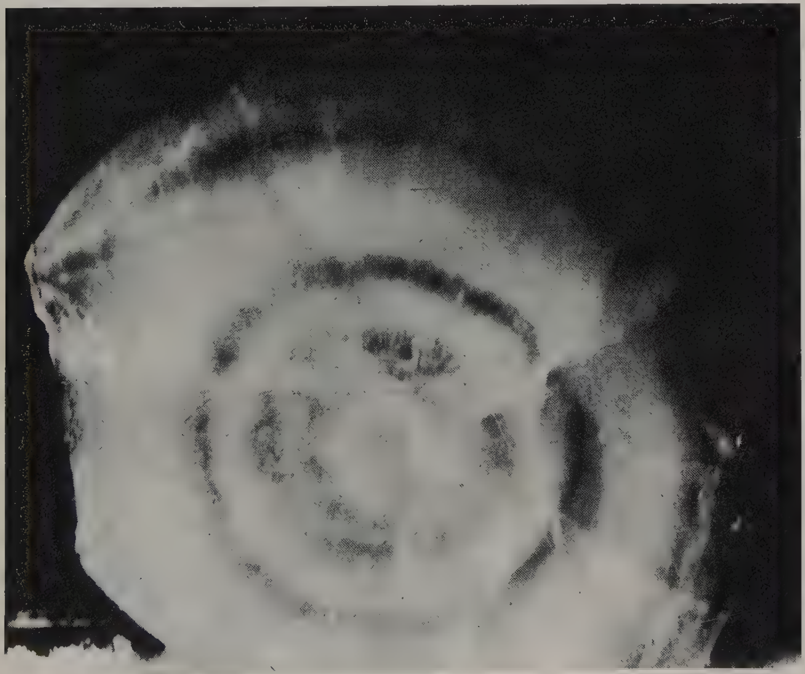


Figure 5–37. This photograph shows a cross section of the layers of ice inside a hailstone. Because of strong upward currents inside a tall cloud, hailstones can become larger than golf balls before they finally fall to the earth's surface.

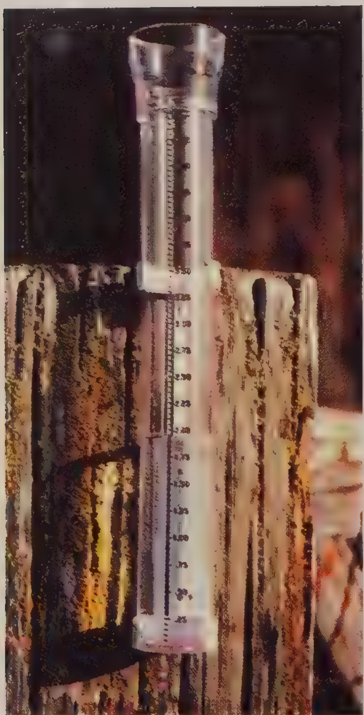


Figure 5-38. Rainwater enters this rain gauge through the opening at the top. What is a rain gauge used for?

Library research

Prepare a report or display on the crystal forms of snowflakes. Consider both the variety and the points of similarity among crystal forms.

dew-point temperature and the air temperature are at or below freezing.

Two other forms of precipitation you may have heard of are sleet and hail. **Sleet** is formed when raindrops fall from warmer air that is over very cold air and freeze into small pellets of ice. Hailstones form only in tall clouds. **Hail** starts off as tiny crystals of ice. But as the bits of ice pass through the different layers of air inside the cloud they pick up more layers of ice or water. There are strong upward currents of air inside the cloud that toss the hailstones back higher into the cumulus cloud. Each time this happens, more layers of ice are added. Eventually the hailstones can get as many layers as an onion. When they get too heavy to be held up, they fall to the earth's surface. When there are very strong upward currents of air in the cloud, the hailstones can become larger than golf balls.

How can a person tell how much precipitation falls at a certain place? The most common way is to measure the precipitation with a **rain gauge.** Rain gauges can be made of steel or plastic and come in many different sizes and shapes. In the rain gauge shown in Figure 5-38, the rain falls into an opening at the top and collects in the cylinder on the bottom.

To measure the amount of a snowfall, several methods can be used. If the snow is about the same depth all over, the simplest way is to insert a ruler into the snow and record the depth. The depth of the snow must then be changed into whatever its value would be in liquid water. Though the water content of a snowfall varies, ten units of snow commonly equals one unit of water. In such a case, 10 cm of snow would contain as much water as 1 cm of rain. The water content of a snowfall can be measured by using a rain gauge. The amount of snow that fell into the gauge is measured and then melted. The amount of water from the melted snow is then compared with the amount of snow from which it came.

Check yourself

1. What causes water to fall from the sky as precipitation?
2. How does sleet form? How does this differ from the way snow forms?

Section 3 Review Chapter 5

Check Your Vocabulary

cirrus clouds
clouds
condensation
cumulus clouds
dew
dew-point temperature
evaporation
fog
frost
hail
heat of fusion
heat of vaporization
humidity
precipitation
rain
rain gauge
relative humidity
saturated air
saturation temperature
sleet
sling psychrometer
snow
stratus clouds
water vapor

Match each term above with the numbered phrase that best describes it.

1. The name commonly used for water as gas
2. The changing from a liquid into a vapor
3. The amount of heat needed for 1 g of a substance to become a vapor
4. The changing of a vapor into a liquid
5. The amount of heat needed for 1 g of a solid substance to melt and become a liquid
6. Air that contains all the moisture it can hold
7. The amount of moisture that is in the air
8. A comparison of the amount of moisture in the air to the amount it can hold
9. An instrument that measures humidity
10. The temperature at which air is saturated
11. Same as saturation temperature
12. Puffy clouds that look like large cotton balls
13. Wispy, feathery-looking clouds
14. Any form of water that falls to the earth
15. Drops of liquid water that fall to the earth
16. Precipitation in the form of flakes
17. Small pellets of ice that form when raindrops fall through cold air and freeze
18. Droplets of water that condense on objects on the earth's surface
19. Ice crystals that form on objects on the earth's surface
20. A cloud that formed on the earth's surface
21. Droplets of water that condense on tiny particles up in the sky
22. Horizontal, layered clouds
23. Layered, round formations of ice
24. An instrument used to measure the amount of precipitation

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. When water changes from a liquid to a vapor, it must ? energy.
   a) lose
   b) take in
   c) give off
   d) radiate
2. In very moist air, ? of the total volume is water vapor.
   a) 100%
   b) 50%
   c) 10%
   d) 3%

Check Your Understanding

1. What are the three physical states of water?
2. Which physical state of water contains the most energy? the least? Explain.
3. How does relative humidity affect the rate of evaporation? Why does this happen?
4. How does air temperature affect the amount of water vapor in the air?
5. Compare condensation and precipitation. How are they similar? different?

Chapter 5 Review

Concept Summary

The atmosphere is a layer of gases that surrounds the earth and that affects energy levels on the earth's surface.

- ☐ The atmosphere is made up of about 4/5 nitrogen and 1/5 oxygen.
- ☐ The air also contains tiny amounts of carbon dioxide, hydrogen, argon, and other gases.
- ☐ Gases and particles of solids in the atmosphere affect the kinds of energy waves from the sun that reach the earth's surface and that remain trapped in the atmosphere.
- ☐ Because the atmosphere is a fluid, it can transfer energy from one place to another by means of convection.

The sun's energy is the energy that is radiated out into space from the sun and that powers the winds and the weather changes that take place within the earth's atmosphere.

- ☐ Almost all the earth's energy comes from the sun.
- ☐ Only a tiny portion of the sun's energy reaches the earth.
- ☐ The sun's energy travels by means of electromagnetic waves.
- ☐ Heat and light are forms of energy.
- ☐ Energy travels by conduction, by convection, and by radiation.
- ☐ Energy is transferred when water changes from one physical state to another.

Water is a compound made up of hydrogen and oxygen, and it can be found on the earth in any of the three physical states of matter.

- ☐ Water changes from one physical state to another.
- ☐ As water changes from one state to another, there is a transfer of energy; energy is either taken in or given off.
- ☐ Most of the water in the atmosphere is found in the troposphere, the zone of the atmosphere that is closest to the earth's surface.

Putting It All Together

1. Draw diagrams that show the wavelengths of three waves (Wave A, Wave B, and Wave C). Wave A has a wavelength one half as long as Wave B. Wave C has a wavelength twice as long as Wave B.
2. When a fluid is heated, what happens to its volume? to its mass? to its density?
3. When uneven heating takes place in a fluid, what causes the warmer portion to rise?
4. More carbon dioxide is being put into the air than ever before. How can this affect conditions on the earth's surface?
5. Between January and June in the Northern Hemisphere, there is a surplus of energy that is stored in the earth's surface. Explain.
6. Water has the highest specific heat of any common natural substance. What does this mean?
7. Name the three kinds of energy transfer and give an example of each.
8. Tell what each of the following instruments measures: dry-bulb thermometer, sling psychrometer, barometer, anemometer, wind vane.
9. By means of the letter L and directional arrows, show how winds in the Northern Hemisphere move in relation to a low-pressure center.
10. How are clouds evidence of temperature differences in the atmosphere?

Apply Your Knowledge

1. A car is left in the sun. All the windows of the car are shut. What happens to the temperature inside the car? Why?
2. Study a room that you are familiar with. How does it receive heat? light? How does it lose heat? How might the room be made more energy efficient?

3. Draw a simple diagram of a solar heating unit for a house. Show how your unit involves energy transfer by radiation, conduction, and convection.
4. Freezer A is a freezer chest. The door of Freezer A is on top and lifts up. The door of Freezer B is in the front of the freezer and swings open like the door of a refrigerator. How does Freezer A compare with Freezer B in terms of energy efficiency? Explain your answer.
5. There is a fire in the building and you have to travel down a portion of a smoke-filled corridor. Which portion of the corridor will have the least amount of smoke? How can you use this knowledge to lessen the danger of breathing smoke into your lungs?

Find Out on Your Own

1. Mark the end of a shadow made out of doors by a stick or pole. Make a second mark that shows where you think the end of the shadow will be in one hour. After an hour, check to see where the end of the shadow is. How close was your prediction?
2. Place several thermometers in the sun. Place a different filter or screen in front of each thermometer. (One thermometer should be in full sun and one should be totally blocked from the sun.) How do the filters affect temperature readings on the thermometers?
3. Place thermometers in various locations in a room—near the ceiling, near the floor, near a window or door, and so forth. Predict which locations will record the highest temperature and which will record the lowest. Then measure the temperatures.
4. Measure the surface temperatures of different objects outdoors on a sunny day. Some objects should be made of different materials. Some objects should be made of the same material but be different colors. Are the temperature readings what you expected? What might explain any differences?
5. Make a wet-bulb thermometer. Experiment with different kinds of cloth, different amounts of moisture, different atmospheric conditions (in sunlight, in front of a fan, and so forth). Do any changes in condition affect the maximum temperature drop?

Reading Further

Adler, David. *World of Weather.* Mahwah, NJ: Troll, 1984.

A comprehensive book of basic information on weather. Topics include tornadoes, hurricanes, evaporation, condensation, rain, snow, hail, and weather forecasting.

Cosgrove, Margaret. *It's Snowing.* New York: Dodd, Mead, 1980.

Explains how snow is made and how crystals grow. Describes avalanches. Great illustrations.

Holford, Ingrid. *The Guinness Book of Weather: Facts and Feats.* Middlesex, England: Guinness Superlatives Ltd., 1984.

A good reference book. Provides clear explanations of all aspects of weather.

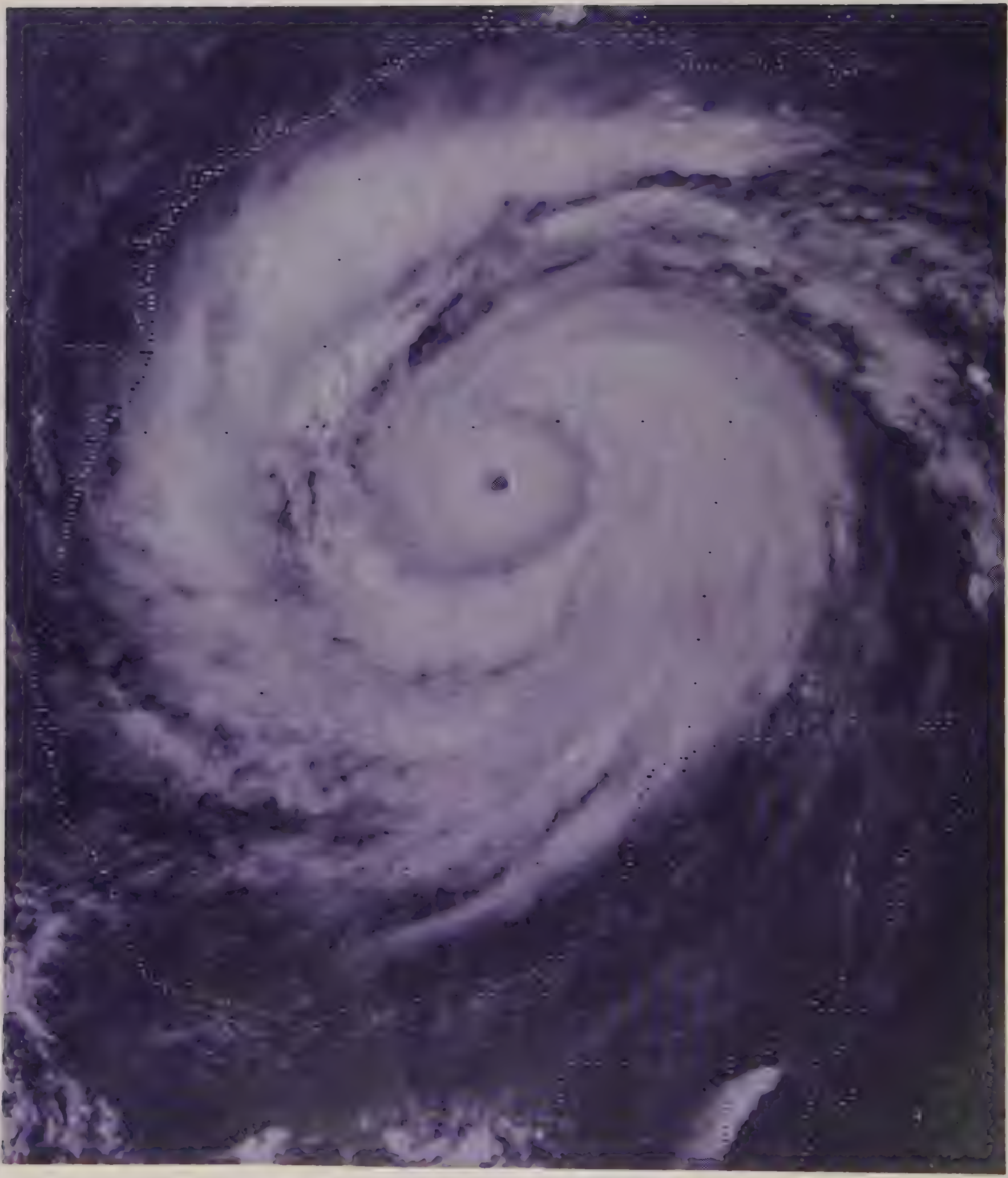
Kals, W. S. *The Riddle of the Winds.* Garden City, N.Y.: Doubleday and Company, Inc., 1977.

A comprehensive textbook on the winds. Traces the effects of the winds on the earth and on people since earliest times. Scientific data, diagrams, and activities.

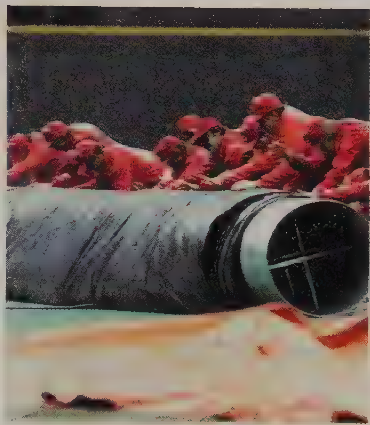
McFall, Christie. *Wonders of Dust.* New York: Dodd, Mead, 1980.

An interesting description of the sources of dust—from within the earth to outer space. Presents problems we have with dust—dust storms, pollution, weather phenomena, and as a possible cause of hailstorms.

Chapter 6



Weather and Climate



Section 1
Air Masses and Weather Fronts

The earth's atmosphere is like an ocean of gases that surrounds the earth's surface.

The earth's atmosphere is made up of large masses of air that are characterized by similar temperatures or moisture content.

When you feel a sudden change in air temperature, or when you see a line of clouds or a thunder-and-lightning storm advancing across the sky, you know by direct observation that an air mass is on the move.

Section 2
Predicting the Weather

Anyone who is planning to do something outdoors must consider what the weather might be like. Will it be sunny or will it be raining? Will it be warm or will it be cold?

A weather report will tell you what kind of weather is likely to occur. It can also tell you how likely it is to occur. But, as with any other prediction, the outcome may not be what was expected.

Section 3
Climate

The climate of an area is determined by the amount of moisture that location receives in an average year and by the average temperatures that can be expected from month to month throughout the year.

Weather data, collected over the years, enables scientists to describe the world's climates. In some instances, the world's climate zones are related, in predictable ways, to geographical location and features. In other instances, surprising variations in climate occur at particular locations.

Until recently, people who studied the weather had to observe it from below. The picture on the facing page shows what a hurricane looks like when seen from above. What kinds of instruments make it possible to observe weather from above. How does this kind of observation affect the ability of scientists to predict tomorrow's weather?

Air Masses and Weather Fronts Section 1

Section 1 of Chapter 6 is divided into six parts:

Air moves in masses

Variations within an air mass

Conditions along a cold front

Conditions along a warm front

A front on top of a front

Stationary and moving fronts

Figure 6-1. A rainstorm is moving across this portion of the earth's surface. What brings local weather to an area?

As mentioned on page 250, two types of winds circulate the atmosphere above your town or city—local winds and prevailing winds. **Prevailing winds,** which are part of much larger patterns of circulation, almost always come from the same direction. In the continental United States, the prevailing winds are westerly. They move from the west to the east across the country.

Local weather is brought to an area by the prevailing winds. Since the prevailing winds generally come from the same direction, what causes changes in the weather? How, for example, is it possible for the same prevailing wind to bring warm air and clear skies one day and cooler air and precipitation on another day?

Air moves in masses

Local weather conditions are brought in by prevailing winds. But weather conditions depend upon characteristics of the air itself. The air that is carried by prevailing winds moves as a unit. It is really a body of air that is moving. This body of air that is carried by the prevailing winds is called an **air mass.**

An air mass is large. It may extend for hundreds of kilometers. Also, the air mass is nearly uniform throughout. This means that all the air has about the same amount of moisture. It also means that all the air is at nearly the same temperature.

The characteristics of a particular air mass depend upon where the air mass forms. In general, air masses form either over land or over water and near a polar region or near the tropics. Four terms used to describe such air masses are *continental, maritime, polar,* and *tropical.* A **continental air mass** is one that forms over dry land (the continent). A **maritime air mass** is one that forms over an ocean. (*Mare* is the Latin word for sea or ocean.) A **polar air mass** is one that forms near the North or South Pole. A **tropical air mass** is one that forms near the Tropic of Cancer or the Tropic of Capricorn.

Each different air mass has its own general characteristics. A continental air mass will contain dry air whereas a maritime air mass will contain moist air, picking up moisture when it forms over an ocean. A polar air mass will contain cold air. A tropical

Library research

Find out which air masses determine the weather where you live. Where do those air masses form? What characteristic weather conditions are caused by these air masses? How do they change with the seasons?

Type of Air Mass	Where Formed	Characteristic of Air Mass
continental (c)	over land	dry
maritime (m)	over water	moist
polar (P)	near a polar region	cold
tropical (T)	near the tropics	hot

Table 6-1. The characteristics of an air mass depend on where the air mass formed. If an air mass formed over water, would it contain moist air or dry air?

air mass will contain warm air. A continental polar air mass will be dry and cold. A maritime tropical air mass will contain both characteristics also (moist and warm).

Figure 6-2 shows the common air masses that affect weather conditions across the continental United States. Note how the letters c (for continental), m (for maritime), P (for polar), and T (for tropical) are used to label the different air masses. An air mass labeled cP is a continental polar air mass. Note also that the arrows show the general direction in which air masses move across the continental United States. This follows the general direction of movement of the prevailing westerlies.

The characteristics of air masses can be related to observed weather conditions. Suppose in your area a cool dry day was followed by a warm humid day. You might infer that a continental polar (cP) air mass was over your area on the first day. Then a maritime tropical (mT) air mass moved in and replaced

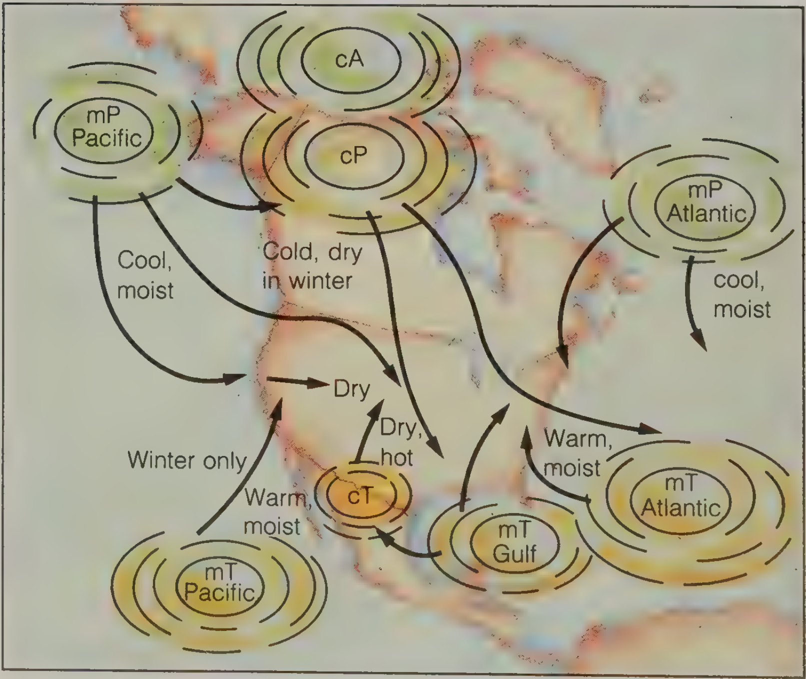


Figure 6-2. Maritime polar air masses, which contain cool moist air, form over the northern Pacific and Atlantic Oceans.

Source region

mP	Maritime polar (Pacific) air masses
cA	Arctic air masses
cP	Continental polar air masses
mP	Maritime polar (Atlantic) air masses
mT	Maritime tropical (Pacific) air masses
cT	Tropical continental air masses
mT	Maritime tropical (Gulf) air masses
mT	Maritime tropical (Atlantic) air masses

the cP air mass. Since air masses can extend for hundreds of kilometers, the same air mass may be over a particular area for several days. Several consecutive days of similar weather would be evidence of this.

As air masses slow down, they may change their characteristics. An example would be a cP air mass originating in Canada. The air would be dry and cold. As it moves south, it would warm up. If it passed over the Great Lakes, it would pick up moisture. (Note that all air masses generally follow the prevailing wind belt. For the continental United States, therefore, air masses tend to move from west to east across the land.)

Check yourself

1. How do air masses affect the weather of an area?
2. How does where an air mass forms affect the characteristics of an air mass?

Variations within an air mass

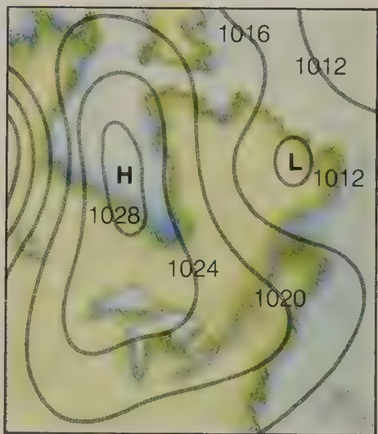


Figure 6-3. The high-pressure area of this air mass is centered over the Hudson Bay region of Canada.

Air masses generally show up as high-pressure areas. But, as shown in Figure 6-3, there may be differences in atmospheric pressure within the same air mass. Low-pressure areas may also be found at the boundaries of an air mass.

Another characteristic of air masses is that, in general, all the air in a particular air mass has the same temperature and the same amount of moisture. Some variations, however, do exist. In Figure 6-3, note that the high-pressure area of the air mass is centered over the Hudson Bay region of Canada. That portion of the air mass would have picked up more moisture than the portion of the air mass that formed over land.

Temperatures within the same air mass can also vary. On a certain summer day, Sault Ste. Marie, Buffalo, and Detroit were located under the same air mass. Their temperatures were as follows: Sault Ste. Marie—73°F; Buffalo—80°F; Detroit—84°F.

Though temperatures and moisture content are not uniform

	Air Mass	Temperature in °F	Relative Humidity
summer	cT	80°F	52%
summer	mT	80°F	93%
winter	cP	0°F	negligible
winter	mP	50°F	66%

Table 6-2. In general, which contain higher relative humidities—continental air masses or maritime air masses?

throughout an air mass, a continental polar air mass is colder and contains less moisture than a maritime tropical air mass. The data in Table 6-2 provides a means of comparing variations among different types of air masses. (Note that the altitude of a city may also affect the temperature and humidity of an air mass over that location.)

Check yourself

1. What are three variations that can occur within an air mass?
2. What can explain differences in amounts of moisture within the same air mass?

Conditions along a cold front

When listening to a weather report, you may have heard the terms *warm front* or *cold front.* A **front** is the boundary between a mass of warmer air and a mass of colder air. Whether the front is a warm front or a cold front depends on which air mass is pushing the other air mass ahead of it.

A **cold front** forms when a cold air mass pushes a warm air mass ahead of it. Cold air is denser than warm air. The warm air is therefore forced upward.

Figure 6-4 illustrates a cold front. Notice the steep slope along the boundary. The warm air is pushed up rapidly. Moisture in the warm air mass condenses to form clouds.

The clouds most commonly found along a cold front are vertical cumulus clouds. The more moisture present in the warm air mass, the larger are the cumulus clouds that form. If enough moisture is present, precipitation will occur.

Precipitation along a cold front tends to be heavy. How long the precipitation will last in an area depends upon how fast the

Library research

What kinds of weather fronts move in over the area where you live? From what direction does each usually come? How can you recognize the approach of each kind of front?

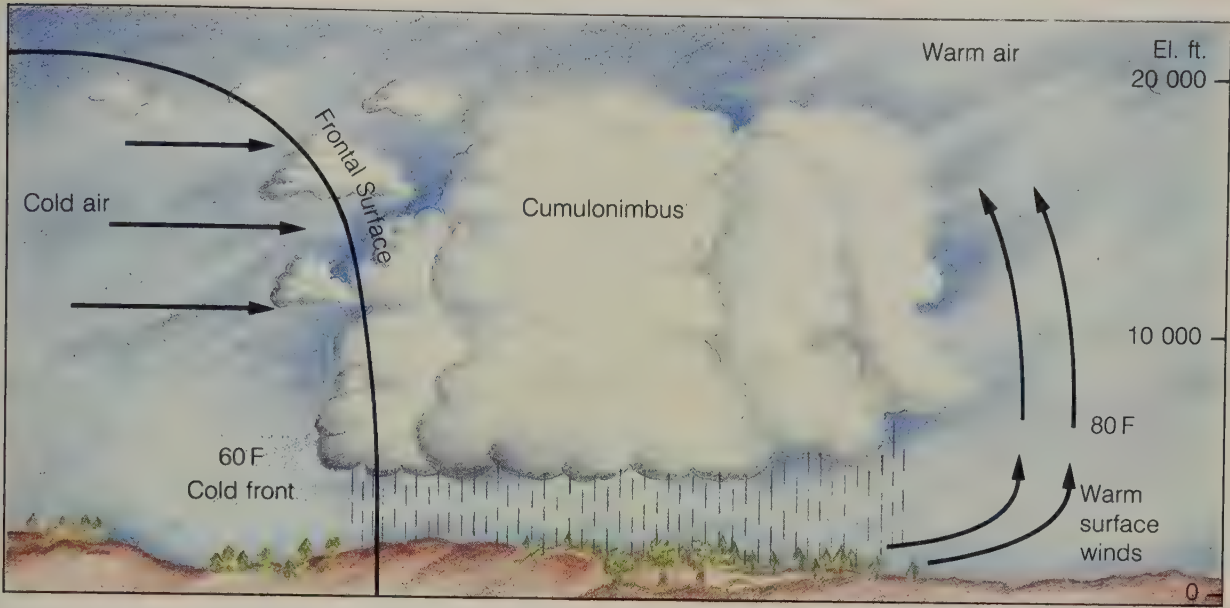


Figure 6-4. A cold front forms when a cold air mass pushes a warm air mass ahead of it. What characteristic of the cold air forces the warm air upward?

front is moving. A heavy thunderstorm may last only a few minutes, or it may continue for a few hours.

Check yourself

1. Describe a cold front in terms of air masses.
2. Why do clouds form along a cold front?

Conditions along a warm front

A **warm front** forms when a warm air mass pushes a cold air mass ahead of it. When this happens, the warm air moves up and over the cold air mass. At the same time, the cold air mass is pushed back.

As shown in Figure 6-5, the boundary line along a warm front slopes more gently than the boundary line along a cold front. Along a warm front, the warm air does not rise as rapidly. The clouds that form along a warm front are usually stratus clouds. These clouds are thinner than cumulus clouds and usually spread over a much larger area.

Precipitation can also occur along a warm front. The precipitation is usually spread over a much larger area than the precipitation along a cold front. Also, a cold front tends to produce thunderstorms of short duration. A warm front produces a steady drizzle that may last for several hours or even longer.

Activity Making a Weather-Front Model

Materials

plaster of Paris, or colored clay

roll of cotton

paint, if plaster of Paris is used

shoebox

masking tape, or labels

plastic wrap

Purpose

To make a model of a weather front.

What to Do

1. Choose the type of front you will represent. (The directions apply mostly to a warm or cold front, but you can figure out how to make an occluded front by looking at Figure 6-6.
2. Make the cold air mass part of the front first. Mix the plaster of Paris with water to make a soft, pasty mass.
3. Pour the mass into one end of the shoebox and shape it. (Use a gradual slope if you are representing a warm front and a steep slope if you are representing a cold front.) Look at Figures 6-4 and 6-5.
4. Allow the plaster of Paris to dry and harden.
5. When the plaster is hard, cover your cold air mass with plastic wrap. Then pour plaster of Paris into the other end of the shoebox to make your warm air mass. The plaster of Paris should cover the plastic near the middle of the box to make a level surface.
6. Before this mass of plaster dries, push cotton on top to represent clouds in the warm air mass. For a warm air front, use a layer of cotton (stratus clouds). For a cold front, roll the cotton into balls (cumulus clouds).
7. When the plaster has completely dried, cut away the shoebox. Separate the two halves and remove the plastic.
8. Paint each of the two halves a different color. You may also want to decorate the lower edge of the sides, using different colors to represent cross sections of trees, grass, buildings, lakes, and so forth.
9. Attach masking tape or labels to your model. Label the various parts of your weather systems (cold air mass, warm air mass, and so forth).

Questions

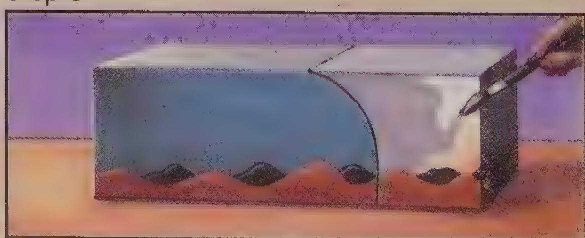
1. How would you arrange the parts of your model to show the front you've chosen?
2. How does the model you made explain the kinds of clouds that form with the front you have shown?

Conclusion

Could your front bring precipitation? Describe the kind of precipitation it would bring.

Step 3

Step 8



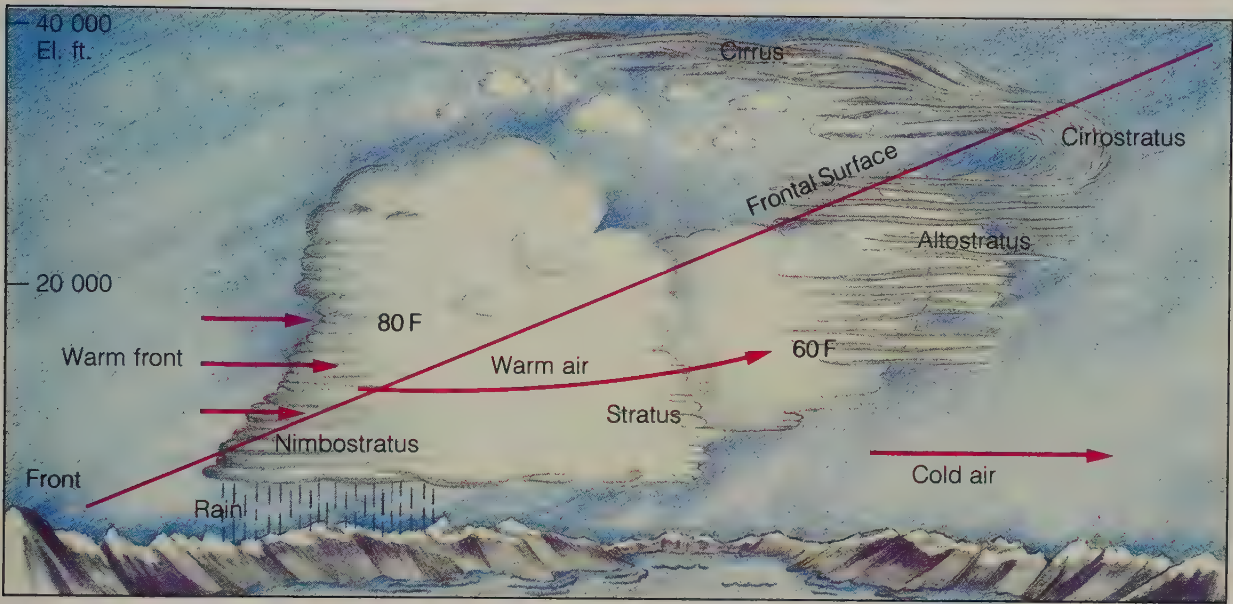


Figure 6-5. A warm front forms when a warm air mass pushes a cold air mass ahead of it. How does the slope of the boundary along a warm front compare to that along a cold front?

Check yourself

1. Describe a warm front in terms of air masses.
2. Why are clouds that form along a warm front thinner and more spread out than clouds that form along a cold front?
3. How does precipitation along a warm front compare with that along a cold front?

A front on top of a front

There is an unusual type of front that sometimes occurs. It forms when a cold front comes up behind and overtakes a warm front. The cold air mass, which is then pushing a mass of less cold air ahead of it, is able to lift the warm air mass completely off the ground. An **occluded front** has formed because the warm front has been cut off or blocked from touching the ground. (The word *occluded* means closed off or shut in.)

Figure 6-6 shows an occluded front. An occluded front may be thought of as a warm front on top of a cold front. The warm front is located above the earth's surface.

Activity Comparing Air Masses Across a Weather Front

Materials

weather map from a newspaper

Purpose

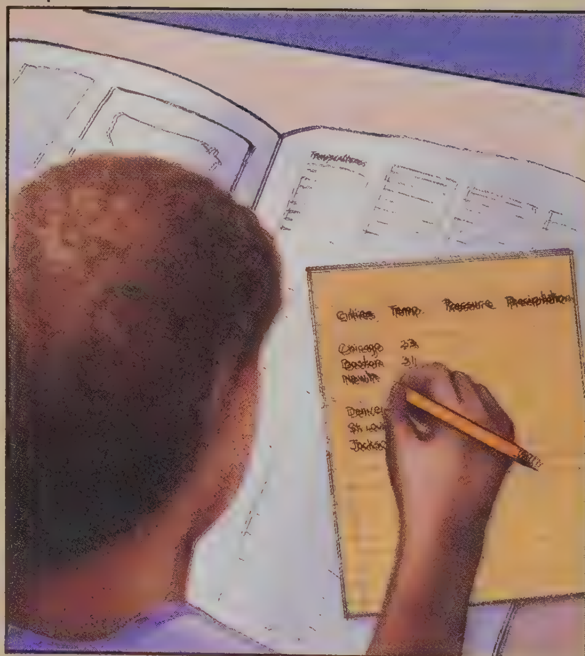
To read a weather map and compare conditions on both sides of a weather front.

What to Do

1. Find and study a weather map in a newspaper.
2. Choose four or six cities, half on one side of a weather front and half on the other. Look for cities with noticeable weather changes from one side of the front to the other.
3. Draw a diagram that shows the cities and the front.
4. Make a data table that gives available information for each city (for example, temperature, atmospheric pressure, cloud cover, precipitation).
5. When you have finished, cover the names of the cities on your data table. Show someone else your diagram and data table and see if she or he can match the cities with the data in the data table.

Step 1

Step 4



Questions

1. Does your weather map show any areas of precipitation? How are these related to weather fronts pictured on the map?
2. Are the conditions across the weather front similar to what you expected? If not, what could be the reason for unexpected findings?

Conclusion

What does your weather map tell you about weather conditions on opposite sides of a front?

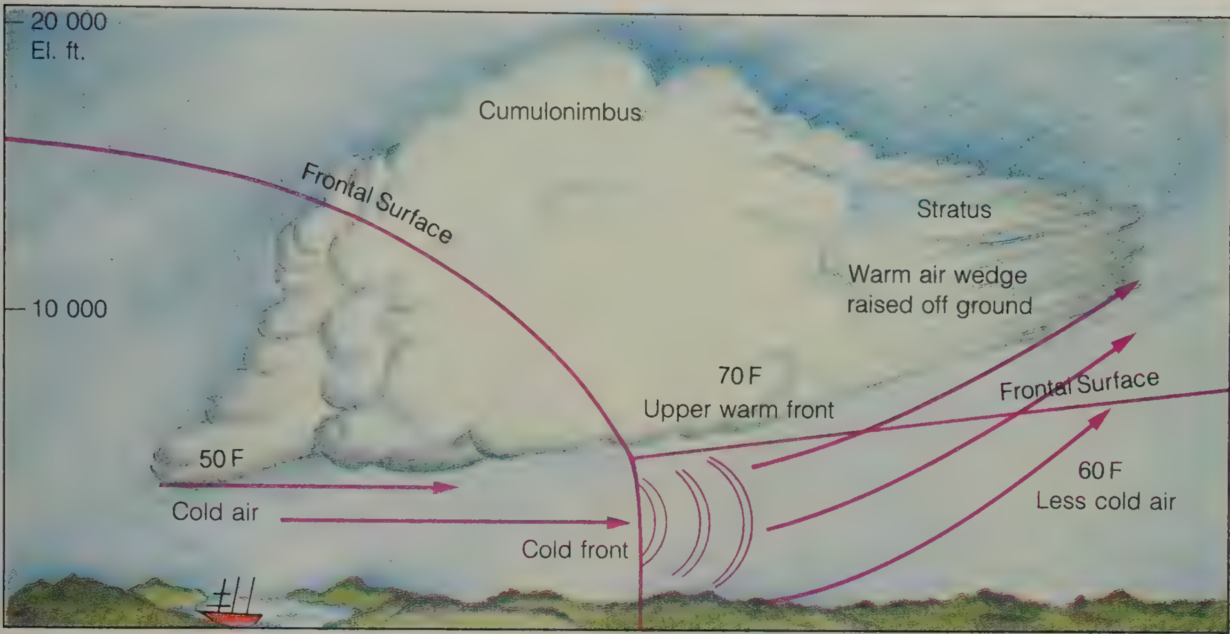


Figure 6-6. Sometimes a cold air mass is able to lift a warm air mass completely off the ground. When this happens, an occluded front forms.

Check yourself

1. Describe an occluded front in terms of air masses.
2. If you were located directly under an occluded front, would the warmest air temperatures occur where you are on the earth's surface or would they occur at some distance above your head? Explain your answer.

Stationary and moving fronts

Sometimes the boundary between a cold air mass and a warm air mass is not moving. Such a front is called a **stationary front.** Either a warm front or a cold front can become a stationary front. This condition may last for only a few hours, or it may last for more than a day.

Often, however, a front moves. It is not difficult to tell when a front is moving through an area. All you have to do is learn to recognize the evidence. The most obvious evidence will be any noticeable changes in the weather.

What is the most obvious evidence that a front is moving through an area?

Figure 6-7 shows how weather conditions change as a cold front moves across an area. At 9:00 a.m., the cold front is approaching City B. Heavy precipitation is occurring at that city. At City A, in the cP air mass, the sky is clear. At City C and City D, within the mT air mass, the sky is partly cloudy. Since City A is located in the cold air mass, temperatures at that city are lower than at City C and City D. (Weather reports for your area

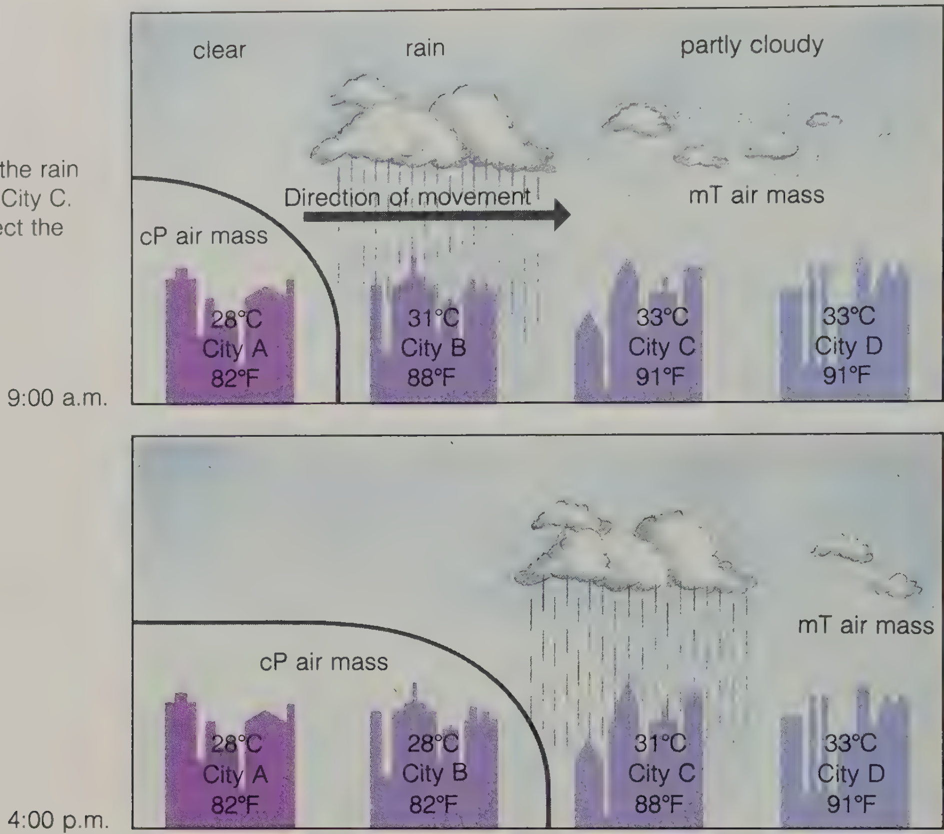


Figure 6-7. By 4:00 p.m., the rain has moved from City B to City C. What time would you expect the rain to reach City D?

most likely give temperatures in °F, degrees Fahrenheit, rather than in °C, degrees Celsius. In this chapter, therefore, temperatures will appear in both °C and °F.)

By 4:00 p.m., the cold front has moved and is bringing rain to City C. The skies over City B have cleared. Notice how the temperatures at City B and City C have dropped since 9:00 a.m. City A, within the cP air mass at both times, shows no change in weather conditions. But City B and City C do show changes. By 4:00 p.m., weather conditions at City C have changed to those that were at City B at 9:00 a.m. Conditions at City B have changed to those that were at City A at 9:00 a.m. Based on the pattern of changes, it is likely that the rain will reach City D between 10:00 p.m. and midnight.

Check yourself

1. What is the most obvious evidence that a weather front is moving through an area?
2. Describe two changes that might occur as a cold front passes over an area.

Section 1 Review Chapter 6

Check Your Vocabulary

air mass
cold front
continental air mass
front
maritime air mass
occluded front
polar air mass
prevailing winds
stationary front
tropical air mass
warm front

Match each term above with the numbered phrase that best describes it.

1. Winds that are part of large patterns of circulation and come from the same direction
2. A large body of air with about the same temperature and amount of moisture throughout
3. An air mass that forms over dry land
4. An air mass that forms over an ocean
5. An air mass that forms near the poles
6. An air mass that forms near the Tropic of Cancer or the Tropic of Capricorn
7. The boundary between two air masses
8. A weather front that forms when a cold air mass pushes a warm air mass ahead of it
9. A weather front that forms when a warm air mass pushes a cold air mass ahead of it
10. A weather front that forms when a cold front advances on and lifts a warm front completely off the ground
11. A weather front that is not moving

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Warm humid air is characteristic of a(n) _?_ air mass.
   a) mP c) cP
   b) mT d) cT
2. Local weather conditions are brought in by _?_.
   a) prevailing winds
   b) local winds
   c) stationary fronts
   d) sea breezes
3. On a weather map, air masses generally show up as _?_.
   a) stationary fronts
   b) occluded fronts
   c) high-pressure areas
   d) low-pressure areas
4. The boundary of a(n) _?_ has a steep slope.
   a) warm front and cold front
   b) warm front
   c) occluded front
   d) cold front
5. _?_ clouds are characteristic of a warm front.
   a) Stratus c) Cumulus
   b) Cirrus d) Cumulonimbus

Check Your Understanding

1. What is an air mass?
2. Why can the same prevailing wind bring different weather conditions on different days?
3. Why do different air masses have different characteristics?
4. What is the relationship between air masses and weather changes?
5. How does a cold front differ from a warm front?

Predicting the Weather Section 2

Section 2 of Chapter 6 is divided into five parts:

Recording the local weather conditions

Weather fronts on a map

Predicting changes in the weather

Difficulties with predicting the weather

Extreme weather conditions

Figure 6-8. Clear skies and plenty of sunshine were predicted, but an unexpected rainstorm has caused an interruption in this game. Why might the weather report have been wrong?

Figure 6-9. Weather stations continuously record atmospheric conditions at a particular location. Data from many such weather stations is transmitted to a weather center where it is processed and used to construct a picture of large-scale weather conditions.

Predicting the weather is an important task. It can help people plan their outside activities. It can also help people prepare for extreme weather conditions that can be dangerous and that can cause great damage.

You can certainly remember instances in which a weather forecast was completely wrong. What happened? Did the forecaster make a mistake? Or did something else probably happen? Why is it so difficult to predict the weather, even with the most advanced equipment? And how much confidence can a person have in any particular weather prediction?

Recording the local weather conditions

Weather can be defined as the condition of the atmosphere at a given place and at a specific time. What is the weather like where you are right now? You might answer with merely a general reaction like "It's great" or "Terrible" or "Raining as usual."

For a more scientific description of the weather, however, you will need to gather and record certain data. Is the sky, for example, clear or cloudy? What is the air temperature? What is the atmospheric pressure? What is the dew-point temperature? Has there been any precipitation? If so, how much? And what about the wind? What direction is it blowing from? And what is its speed?

If you were to gather the data needed to answer just these questions, you would be performing the job of an observer at

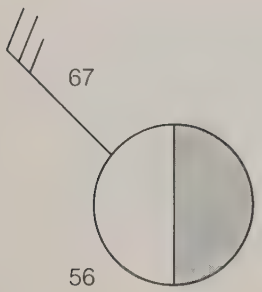


Figure 6-10. This is an example of a station model. What does the stick part of the flag indicate?

a weather station. There are many thousands of weather stations all around the world. Each of these stations continuously measures and records atmospheric conditions at that particular location. Conditions at each weather station are recorded simply and clearly by means of a set of symbols that make up a **station model.**

Figure 6-10 shows a sample station model.

1. The circle in the middle is half darkened. This means that half the sky is covered with clouds.
2. The number at the upper left is the air temperature. In this case, the air temperature is 67°F.
3. Below the air temperature is the dew-point temperature, which is 56°F.
4. At the upper right is the atmospheric pressure. It has been abbreviated. The value 128 has been shortened from 1012.8 millibars. To get the true atmospheric pressure of pressures of 1000 mb or higher from a station model, you must move the decimal point one digit to the left (changing the number from 128 to 12.8, for example) and then add 1000.
5. The number beneath the atmospheric pressure is the amount of precipitation, which is commonly measured in inches. In this case, the station model indicates that there has been 1.20 inches of precipitation.
6. The position of the stick part of the flag indicates the wind direction. In this case, the wind is blowing from the northwest.
7. The wind speed, commonly given in knots (nautical miles per hour), is indicated by the number of cross marks on the flag. Each long mark represents 8-10 knots. Each short mark represents 3-7 knots.

The symbol in Figure 6-10 indicates a wind speed of about 25 knots per hour. (1 nautical mile = 1 minute of arc of a great circle of the earth or 1852 meters or 6076.1 feet or 1.15 miles.)

Check yourself

1. What kinds of information are indicated on a station model?
2. How can you determine wind direction and speed from a station model?

Weather fronts on a map

In the United States, information from each different weather station is transmitted to central data banks. There the data is compiled and analyzed with the help of computers. In addition to ground recording stations, other sources of information are used. Radar and satellites photograph and track large-scale air movements. Weather balloons measure weather conditions higher in the atmosphere. All this information is transferred to weather maps. By means of certain symbols, a single weather map can indicate atmospheric conditions above a large portion of the earth's surface.

Figure 6-11. Satellites are able to photograph and track large-scale air movements.

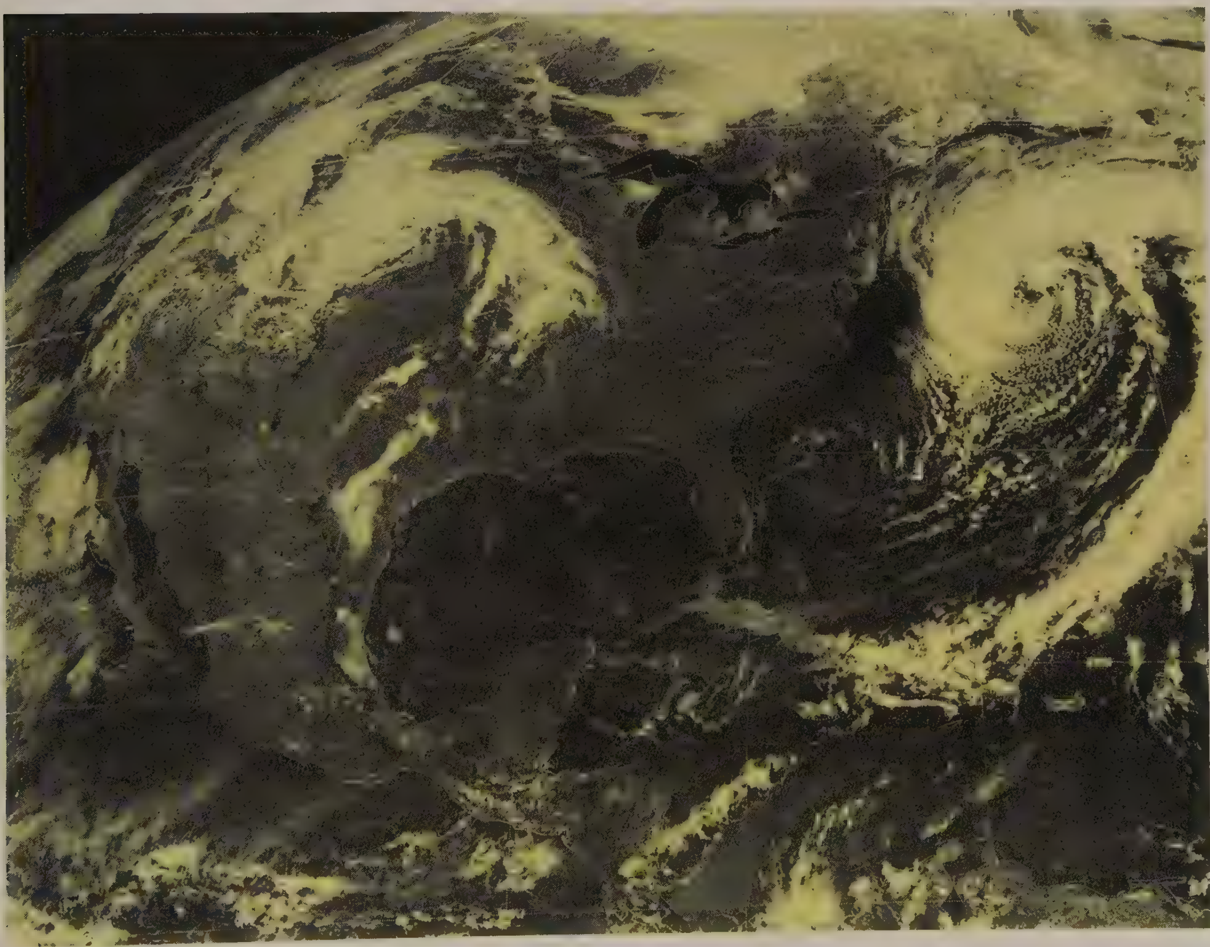
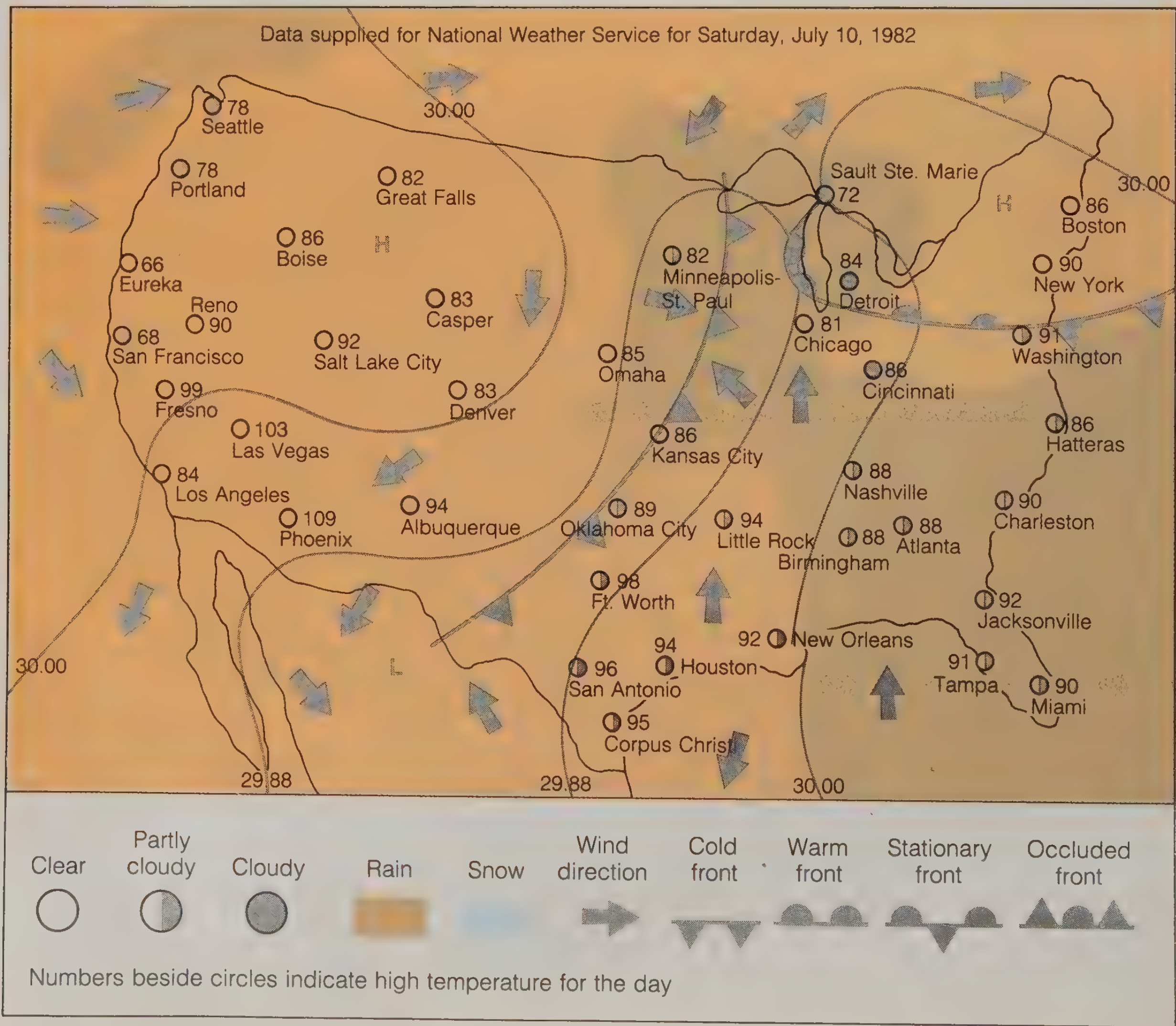


Figure 6-12 indicates a newspaper forecast of atmospheric conditions over part of the continental United States on Saturday, July 10, 1982. Listed below the map are meanings for the various symbols used on weather forecast maps.

Find the weather front that stretches from near San Antonio up toward Minneapolis-St. Paul. As explained below the map, the triangles indicate that this is a cold front. And the fact that the triangles are to the south of the front indicates that the cold front is moving southward. Cold air north of the front is pushing warm air south of the front.

Figure 6-12. What kind of weather front stretches from near San Antonio up toward Minneapolis-St. Paul?



Notice how air temperatures compare across the cold front. 94°F is predicted for Little Rock, which is ahead of the cold front. For Kansas City, at the boundary of the cold front, an 86° temperature is predicted. And for Omaha, behind the cold front, 85° is predicted.

Figure 6-12 also shows another type of weather front, stretching from Sault Ste. Marie south and east toward Washington, D.C. As explained below the map, the semicircles indicate that this weather front is a warm front. And the position of the semicircles along the north side of the front indicates that the warm front is moving northward. Warm air from the south is pushing cold air from the north.

What kind of weather front is indicated by semicircles?

Predicted air temperatures for Cincinnati, Detroit, and Sault Ste. Marie indicate lower temperatures for cities in the cold air mass that is ahead of the warm front.

Notice what happens to the weather front as it continues to the east of Washington, D.C. It changes from a warm front to a cold front. The triangles indicate that the front that extends from Washington, D.C. to the right-hand edge of the map is a cold front and that it is pushing southward.

Look at the other symbols below the map. Notice the symbols that would be used if a stationary front or an occluded front were predicted. For a stationary front, symbols for a warm front and a cold front are combined and are shown as pushing against each other. A stationary front, therefore, does not move in either direction.

The symbol for an occluded front also combines the symbols for a cold front and a warm front. But in an occluded front, the symbol shows that both the cold front and the warm front are moving in the same direction. (In an occluded front, as mentioned earlier, the warm front is located above a cold front.)

Check yourself

1. What are four sources that provide data for central weather data banks?
2. Looking at a weather front on a weather map, how can you tell on which sides of the front the warm and cold air masses are located? Mention two ways.

Activity Plotting Changes on a Weather Map

Materials

weather maps from old newspapers, for any three consecutive days

blank map of same area as shown on the weather map

3 colored pencils (different colors)

Purpose

To predict weather patterns based on weather maps.

What To Do

1. Look at the weather map for the first of the three days.
2. Find the high-pressure and low-pressure centers. Look at the isobars around these centers. Note how the atmospheric pressure changes as you move away from each of these centers. Draw the centers and isobars on your blank map with a colored pencil.
3. Locate and identify the weather fronts on the first map. Draw and label these fronts on your map, using the same pencil you used in step 2. Mark the colder and warmer air masses on opposite sides of each front.
4. In another color, draw the pressure centers and weather fronts for the second day. Compare the way that the pressure centers and weather fronts moved from one day to the next.
5. From what you have drawn on your map, predict where those pressure centers and weather fronts will be on the third day. Draw these predicted locations in a third color.

Questions

1. Using your first day's map, look at temperatures on opposite sides of the fronts. Do the differences in temperatures match your labeling of the air masses?
2. Which way do winds usually blow near high-pressure and low-pressure centers? Check the first day's map to see if this pattern is true in this case. Is it?
3. Where on the map do you find cities with cloudy skies? with clear skies? Is this what you would expect?
4. What other inferences can you draw about weather conditions from the first day's map?
5. How does the map you drew compare with the newspaper's weather map for the third day? Were your predictions accurate?

Conclusion

How well can you predict the weather by reading weather maps?

Step 1

Step 2

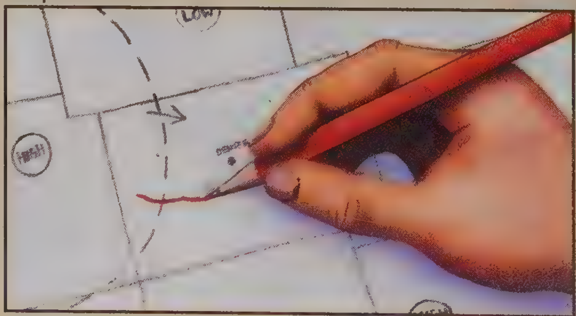


Figure 6-13. What kind of weather front extends from near San Antonio to near Oklahoma City?

Predicting changes in the weather

What are two uses for a weather map?

A weather map can be used to interpret current weather conditions. It can also be used to predict how the weather will change in the next few days, especially when used along with weather maps for the preceding day (or days) and along with information gathered by satellites and by radar.

As an example, let's compare weather conditions forecasted for July 10, 1982 (Figure 6-12) and July 12, 1982 (Figure 6-13). Compare the position of the weather fronts on the two maps. By July 12, you will note, the major weather front has pushed down in a southeastward direction. From near San Antonio to near Little Rock, the front has become stationary. From Nashville, a cold front curves northward into Canada.

Notice also what has happened to the rainy areas. For July 12, most of the rain was once again predicted to fall ahead of the cold front. But the advancing cold front has pushed the area of rainfall eastward. And the high-pressure center that was near Salt Lake City has moved eastward to Kansas City, bringing clear skies to the cities behind the cold front.

The map in Figure 6-13 also shows how the advancing cold front is expected to affect air temperatures. For July 12, cooler

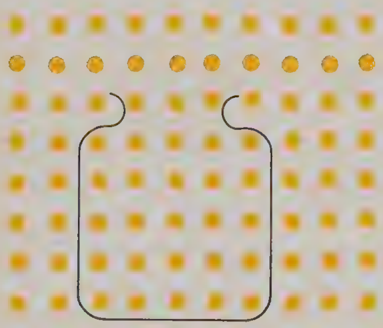
temperatures have been predicted for Cincinnati, Chicago, Detroit, and other cities that will have come within the advancing mass of cold air.

Based on these two weather forecast maps, you can see that within the next day or so, Boston, New York, and Atlanta will probably have clear skies and cooler temperatures. At the same time, however, you will notice that another cold front is moving in an easterly direction toward Seattle and Portland in the Pacific Northwest.

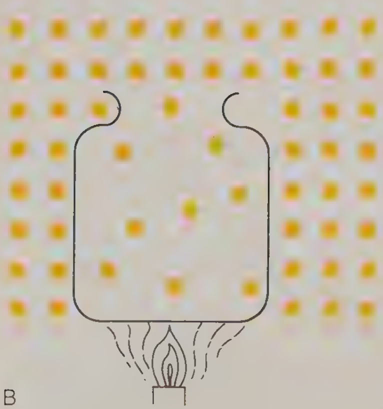
Check yourself

1. What are some types of information provided by weather maps?
2. How can weather maps be used to predict the weather?

Figure 6-14. As the air spreads out from heating, there are fewer molecules per unit volume to exert pressure.



A



B

Difficulties with predicting the weather

Predicting weather conditions is a very complex task. Many factors affect the weather. At some time, you may have observed the following to occur. You listen to a weather forecast. It predicts rain for the following day. When that day comes, the skies are cloudy, but no rain falls. To understand what might have caused the incorrect weather prediction that you heard, it is necessary to understand something about the relationships among weather variables.

Let's begin by considering the relationship between two simple weather variables, temperature and pressure. When the air temperature becomes warmer, the air expands. When air expands, it spreads out, exerting less atmospheric pressure on the earth's surface. We may conclude that as air gets warmer, the air pressure (atmospheric pressure) drops. We may also conclude that as the air temperature drops, the air pressure increases.

We say that temperature and pressure in the atmosphere are inversely related. The word *inversely* means "in ways that are directly opposite." As one goes up, the other goes down. And as one goes down, the other goes up.

But this relationship between temperature and pressure in the atmosphere does not always happen. Let's say that you take temperature readings on Monday and Tuesday morning. Tuesday's reading shows an increase in temperature. But your measurements of atmospheric pressure taken at the same time show that the pressure has not decreased. It may have remained the same. It may even have gone up. In either case, this is not what you expect.

The explanation for this can be related to changes among other weather variables. Atmospheric pressure, for instance, is also affected by the amount of moisture in the air. If the air becomes drier, the atmospheric pressure will rise. Suppose this is what happened between your Monday and your Tuesday readings. The temperature rise caused the atmospheric pressure to drop. But the loss of moisture in the air caused the atmospheric pressure to rise. These two changes were offsetting each other. If the greater change was a loss of moisture, the overall change would be a small increase in pressure.

Relationships among air temperature, atmospheric pressure, and moisture content affect the weather. Add to this other factors such as wind direction and you can begin to see why predicting, or forecasting, the weather is not an easy task.

What factors make it difficult to predict the weather?

Given the many difficulties connected with predicting the weather, how can weather forecasts be made? They are made on the basis of probabilities. You may have heard a weather report indicate a 70% chance, or a 70% probability, of rain for the following day. At another time, the prediction may have been for a 50% chance of rain. In both cases, rain is possible. In the first case (the 70% chance of rain), the forecaster, after analyzing all the weather data, decided that it was more likely that it would rain than that it wouldn't rain.

We can never be absolutely certain about any weather prediction. Variations are always possible. It is, of course, the big variations that are most noticeable. There may, for example, have been a time when the local forecast called for clear skies with only a slight chance of rain for the next day. But then, during the night, the wind direction changed. The next day, there was a heavy thunderstorm.

Computers have allowed scientists to greatly improve the accuracy of weather forecasts. Information can be processed and

Activity Tracking Severe Weather Conditions

Materials

newspapers, magazines, radio, television, blank maps

Purpose

To understand how severe weather conditions occur and how they affect people.

What to Do

1. Severe weather conditions occur throughout the world. Look for reports of a severe weather condition somewhere on the earth.
2. Using newspaper, television, and radio reports, track the movement of the severe condition. Plot its path on a blank map.
3. Note any other accompanying weather conditions. Also note the weather in the affected areas both before and after the severe conditions. Record these conditions on your map, too.

Questions

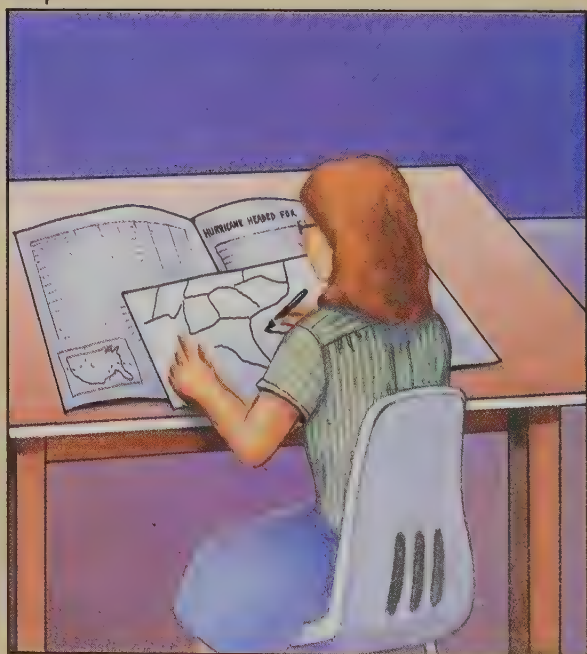
1. How were people affected by the severe weather conditions? Was there any property damage? If so, what kind of damage? What was the estimated cost of the damage?
2. If some areas were affected more than others by the severe weather, was any explanation offered? If so, what?
3. What kinds of precautions were taken in the affected areas? Were they helpful?
4. What else might have been done to reduce losses?

Conclusion

What have you learned about severe weather conditions? What do they do to the environment? to people?

Step 1

Step 2



analyzed much more quickly. But even with future advances, we will probably never be able to forecast the weather with 100% accuracy. There are just too many small variations possible. Over the long run, however, accurate weather forecasts from professional sources will outnumber the cases in which they were wrong.

Figure 6-15. Computers allow scientists to process and analyze large amounts of data very quickly.

Check yourself

1. Name four variables that make predicting the weather a very complex task.
2. What happens to the atmospheric pressure when air gets warmer?
3. What happens to the atmospheric pressure when the moisture content of the air increases?
4. Over the long run, how accurate can we expect weather forecasts from reliable sources to be?

Extreme weather conditions

From time to time, unusual combinations of atmospheric conditions produce extreme and dangerous weather conditions. Thunderstorms and blizzards are produced by unusual atmospheric conditions. Tornadoes and hurricanes are also produced by unusual atmospheric conditions. In all such cases, advance warning by weather forecasters can save lives and property that would otherwise be lost.

Thunderstorms. Thunderstorms are produced by large rising columns of warm moist air. You may recall that cumulus clouds are produced by condensation from warm moist rising air. Sometimes these updrafts are so strong that the cloud may extend 300 m or more. These massive clouds are called **cumulonimbus clouds.** (When *nimbus* is part of the name of a cloud, the cloud is a rain cloud.)

Cumulonimbus clouds contain huge amounts of moisture. They can produce a torrential downpour. The larger the cloud

Figure 6-16. What causes lightning in a cumulonimbus cloud?

and the more moisture present, the heavier will be the precipitation. When accompanied by thunder and lightning, the resulting storm is called a **thunderstorm.**

Lightning and thunder are found in a cumulonimbus cloud. **Lightning** is a flash of light produced because static electrical charges build up in different parts of a cloud. When these charges jump from one part of the cloud to another part of the cloud or to the ground, lightning results. At the same time, the lightning causes a rapid expansion of the air it passes through. This rapid expansion of air produces a loud rumbling noise called **thunder.**

Thunderstorms usually occur in the warmer summer months. The heating of the air near the ground adds to the rapid upward movement of air. The most severe thunderstorms usually occur near a cold front. Air is pushed up more rapidly along a cold front.

Figure 6-17. Air temperature is usually the best indicator as to whether precipitation will be in the form of rain or snow.

Blizzards. If the air temperature is below freezing, conditions similar to thunderstorm conditions can produce a **blizzard.** During a blizzard, much snow may fall in a few hours. At the same time, strong winds can blow the snow into very deep drifts.

Tornadoes. A **tornado** is a funnel of air that extends down from a cumulonimbus cloud. The winds in a tornado travel in a circular direction at speeds of up to 800 km per hour. When a tornado touches the ground, it can cause extensive damage. The wind speeds are so great at times that cars may be lifted off the ground and the roofs of houses may be blown off. The air pressure inside the tornado is very low.

The funnel cloud of a tornado is usually only 100 m or less in diameter. Points along the direct path of the tornado may be completely leveled. At the same time, points 1 km away may be relatively untouched.

In the United States, tornadoes occur most frequently in the Midwest. More than one thousand tornadoes a year occur in

Library research

Research other extreme weather conditions such as typhoons or waterspouts. Are the extreme conditions you chose limited to certain areas of the world? to certain times of the year?

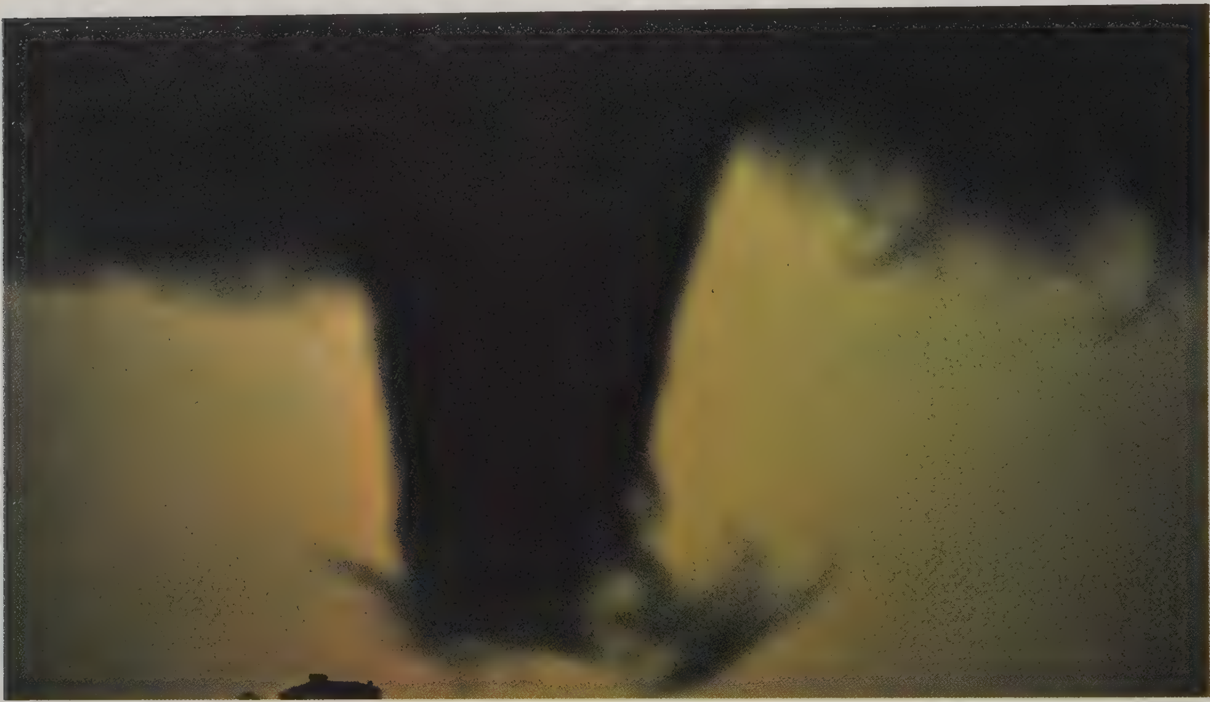


Figure 6-18. Buildings have actually been known to explode when hit by a tornado. What causes this to happen?

that area. Most of them are small or occur in relatively isolated areas. If, however, a powerful tornado hits a large city, great damage may result.

Cities and towns in the "tornado belt" usually have advance warning systems to warn the people if a tornado is approaching. This permits enough time for people to find shelter in basements or other safe underground locations.

What are hurricanes?

Hurricanes. **Hurricanes** are very large circular storms with wind speeds of at least 64 knots (118 km/hr) and extremely low pressure at the center. Wind speeds may reach 150 km per hour or even greater. A hurricane is accompanied by dense clouds and heavy rain. The diameter of a hurricane is much larger than that of a tornado. The high winds of a hurricane may affect an area as wide as 300 km.

Being a low-pressure center, hurricane winds travel in toward the center of the hurricane. At the center, which may be several kilometers across, the air is traveling upward. As a result, weather conditions in the center, or "eye," of the hurricane may be relatively calm.

Figure 6-19. Hurricanes and typhoons can cause ships to run aground and can cause great damage along seacoasts.

Hurricanes that reach the United States form over the Caribbean Sea or over the Gulf of Mexico. They travel westward or northwestward at a rate of 10-20 km per hour. Hurricanes can cause great damage along the coasts. The strong winds produce huge ocean waves that pound the coast and flood low-lying areas. Hurricanes also cause great damage when they pass inland and travel across the land.

Some hurricanes are weak and do not last long. Such hurricanes obviously do less damage than strong hurricanes. Some hurricanes remain out over the ocean and do not approach land as they travel northward from their place of origin. These hurricanes are a much greater danger to ships on the sea than they are to people and property on the land. In any case, modern tracking methods keep a careful watch on a hurricane's position and on any changes in its force and in the course along which it is moving.

Check yourself

1. Why do thunderstorms often occur during summer months?
2. How do tornadoes and hurricanes compare in terms of wind speed, size of area affected, and air pressure at the center?

Section 2 Review Chapter 6

Check Your Vocabulary

blizzard	station model
cumulonimbus cloud	thunder
hurricane	thunderstorm
lightning	tornado

Match each term above with the numbered phrase that best describes it.

1. A set of symbols used to record conditions at a weather station simply and clearly
2. A storm produced by large rising columns of warm moist air and characterized by thunder, lightning, and heavy precipitation
3. A massive vertical cloud containing much moisture; associated with thunderstorms
4. A flash of light produced when static electrical charges jump from one part of a cloud to another or from a cloud to the ground
5. A noise caused by the rapid expansion of air as lightning passes through it
6. A storm produced when thunderstorm conditions occur at below freezing temperatures; characterized by heavy snow and strong winds
7. A narrow funnel of air extending down from a cumulonimbus cloud
8. A very large circular storm with wind speeds of at least 64 knots

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Each long mark on a station model wind speed indicator represents _?_.
   a) 3-7 knots
   b) 8-10 knots
   c) 8-10 miles per hour
   d) 8-10 km per hour
2. Millibars (mb) are used to measure _?_.
   a) air temperature
   b) wind speed
   c) air pressure
   d) relative humidity
3. Lower temperatures can be expected _?_.
   a) behind a stationary warm front
   b) behind an advancing warm front
   c) ahead of an advancing cold front
   d) behind an advancing cold front
4. Extreme _?_ at the center of a tornado may cause a building to explode.
   a) amounts of snow
   b) amounts of rain
   c) high pressure
   d) low pressure
5. Weather conditions in the center a _?_ may be relatively calm.
   a) thunderstorm
   b) tornado
   c) hurricane
   d) blizzard

Check Your Understanding

1. How do station models affect large-scale weather maps?
2. Are triangles used to indicate a warm front or a cold front? What else do the triangles on a weather front indicate? How do they do this?
3. Draw the symbols for an occluded front and a stationary front. How are they similar? How are they different?
4. What does it mean when two variables are inversely related?
5. How are probabilities useful in making weather predictions?

Climate Section 3

Section 3 of Chapter 6 is divided into four parts:

General types of climates

Factors that affect temperature

Factors that affect moisture

Climate graphs

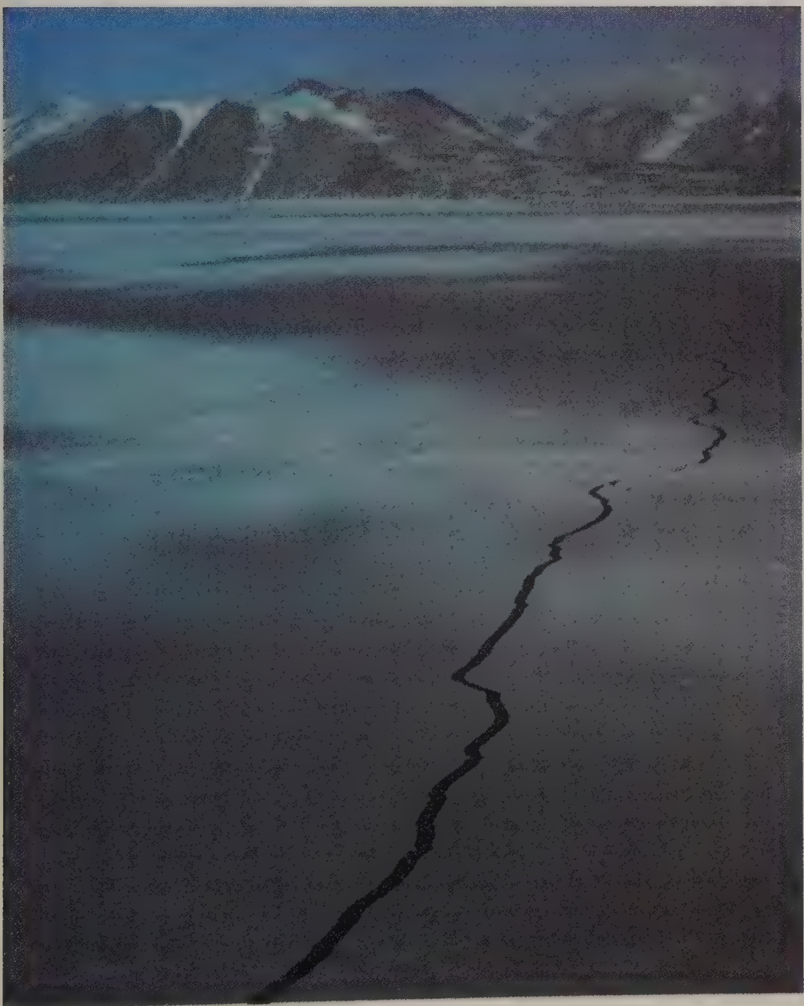


Figure 6-20. A crack crosses the frozen surface of McMurdo Sound, Antarctica. In Antarctica, snow and ice cover the earth's surface every day of the year, year in and year out. How does the climate of Antarctica differ from the climate where you live?

How are weather patterns related to climate?

How do weather and climate differ? **Weather** is the atmospheric conditions at a particular location at a particular moment in time. Weather conditions relate to the here and now. And weather conditions are subject to sudden and very noticeable changes.

Climate, on the other hand, is not concerned with immediate weather conditions. Climate is concerned with long-term patterns. **Climate** is concerned with weather patterns that occur in one place over a period of a year or longer.

What kind of climate do you live in? What factors determine the climate where you live? And what effect does the climate have on life in your area?

General types of climates

Library research

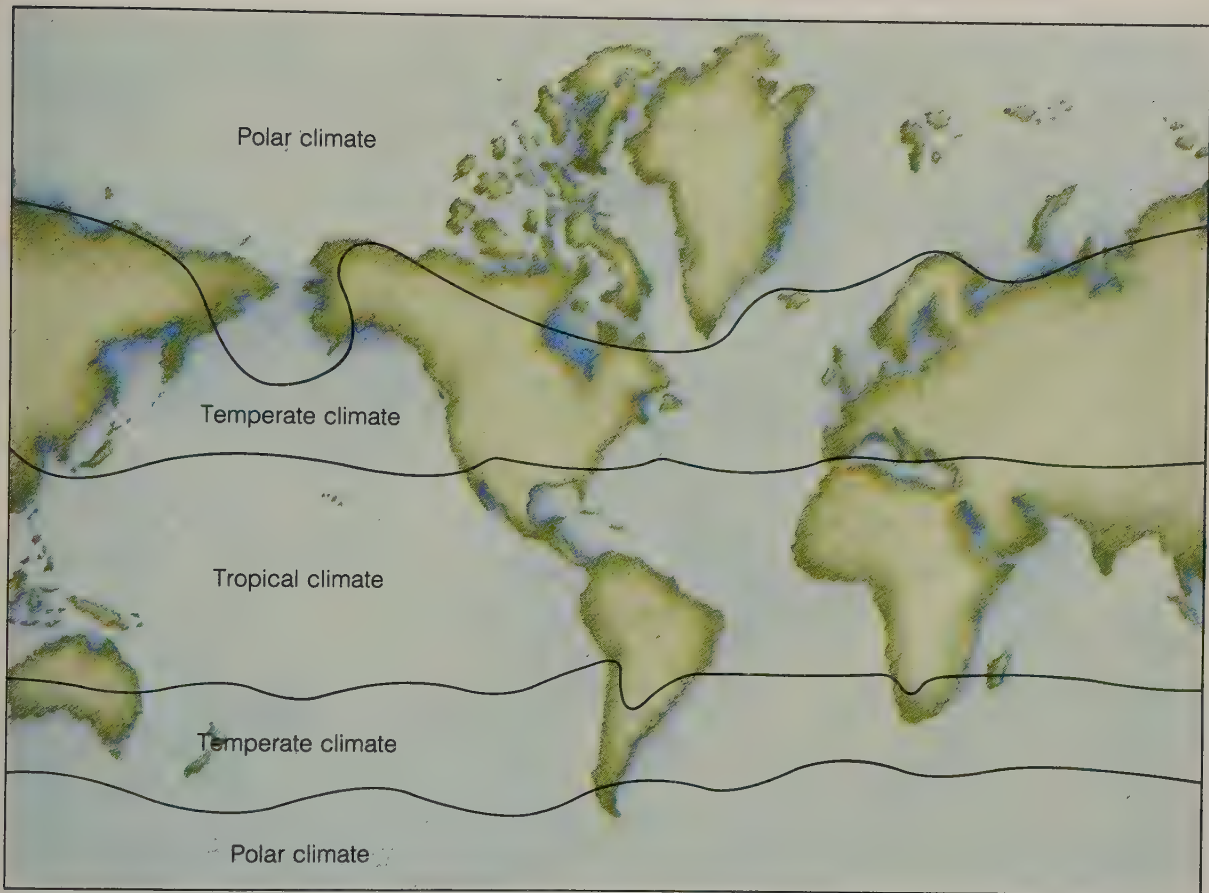
Pick a region on the climate map (Figure 6-21). Research the various climate factors for that region and explain how they combine to produce the climate for that region.

Any climate of the world can be classified according to two basic factors. One basic factor of climate is temperature. Over the long run, are air temperatures at a certain location hot or cold? The other basic factor of climate is the amount of moisture or precipitation. Over the long run, is the weather wet or dry? Different combinations of hot or cold and dry or wet provide a simple way of considering the earth's major climates.

In general, temperatures are directly related to latitude. As the latitude decreases, average temperatures increase. Highest average temperatures can, in general, be expected to occur at locations near the equator (0° latitude). Lowest average temperatures can be expected to occur near the North Pole (90° N latitude) and the South Pole (90° S latitude).

Figure 6-21 shows three major climate zones, based largely on average temperatures. Temperatures in these three zones are the result of the kind of air mass commonly found there. Tropical air masses are found in a **tropical climate.** A tropical climate, therefore, has the warmest temperatures. In a tropical climate, the average temperature during the coldest month does not drop below 18°C (67°F).

Polar air masses are found in a **polar climate.** Therefore, as you'd expect, a polar climate has the coldest average temperatures. In a polar climate, the average temperature during the warmest month does not rise above 10°C (50°F).



In between these two extremes of climate, in the middle latitudes, is a **temperate climate.** Temperatures in this climate are affected by both tropical and polar air masses. Average temperatures in a temperate zone are moderate, in between the average temperatures of the polar and tropical zones.

Figure 6-21. Here is one way of dividing the earth's climates into general zones. Are these three divisions based on average temperatures or on average amounts of moisture?

The other basic factor that affects climate is the average amount of precipitation that falls in a certain area over a period of time. Two kinds of air masses affect the amount of precipitation an area receives: maritime air masses and continental air masses.

In general, areas that lie near large bodies of water will receive more precipitation than other areas. Maritime air masses are commonly found near large bodies of water. The climate in such areas is called a **marine climate** or oceanic climate.

How does a continental climate differ from a marine climate?

There are also areas of land that do not receive moisture that evaporated from a large body of water. Continental air masses are commonly found in such areas. These areas experience a **continental climate,** which is a drier climate than a marine climate. The amount of moisture is the distinguishing factor between a marine climate and a continental climate.

Check yourself

1. What are the two basic factors that determine climate?
2. What three climates are distinguished by average temperatures?
3. What two climates are distinguished by average amounts of moisture?

Factors that affect temperature

In general, average temperatures decrease as latitude increases. There are, however, other natural factors that affect temperatures at a particular location. Two such factors are altitude and nearness to ocean currents.

Altitude. The lower layers of the atmosphere are heated by radiation from the earth's surface. Particles in the atmosphere trap this heat from the earth and exercise a kind of greenhouse effect on the layers of air closest to the earth's surface. The greenhouse effect is most noticeable at elevations close to sea level. As you go higher above sea level, the air gets colder.

The average temperatures at cities at high elevations are a few degrees cooler than they would be at sea level. Temperatures at the top of a mountain are many degrees colder than the temperatures at the base of the mountain. Because of this you can find a snow-covered mountaintop very close to the equator. It's a matter of altitude.

Temperatures on a mountaintop may also be affected by the fact that the land area on a mountaintop is so small in comparison to the air that surrounds it. Since the air is heated by heat from the land, less heat will be radiated back into the atmosphere from a mountaintop than from a larger surface of land.

The place with the hottest average temperatures in the United States is Death Valley, located in California. Death Valley also has the lowest elevation of any place in the United States. At its deepest, Death Valley is about 90 m below sea level.

In addition to its low elevation, Death Valley's southern location and its location in a valley surrounded by mountains also affect its temperature. Because of its southern location, all exposed land surfaces (including the surrounding mountainsides) receive more direct rays from the sun than locations farther to the north. And because Death Valley is located in a valley, the air that descends into the valley warms up as it loses altitude.

Descending air warms up because air pressure at lower altitudes is greater than at higher altitudes. As the air pressure becomes greater, the molecules of air become more closely packed together. They therefore collide into each other more

Figure 6-22. Snow covers the top of Mount Rainier in Mount Rainier National Park, Washington. How can there be snow at the top of the mountain and blooming flowers at lower elevations?

How does warming by means of conduction, which involves a heat exchange, compare with adiabatic warming?

frequently and cause the air to become warmer. If you have ever used a bicycle pump to pump up a tire and noticed the bicycle pump becoming warmer as you used it to pump up the tire, you have experienced this warming of air as pressure increases. This type of warming is called an **adiabatic change** (ad′-ee-uh-BAT′-ik) because the temperature change of the air was caused solely by a compression of the material and not by any heat exchange with other material in its surroundings.

As air rises, just the opposite happens. The atmospheric pressure decreases. The air expands. The air molecules become more spread out and collide less frequently. The air becomes cooler without any heat exchange with surrounding material. This type of cooling, which was caused solely by the expansion of the material, is also called an adiabatic change.

What causes Bermuda to have a warmer climate than locations at the same latitude on the mainland of the United States?

Ocean currents. Another factor that influences temperatures is nearness to ocean currents. The surface temperature of water affects the temperature of the air above. Cool water will cool the air. Warm water will warm the air.

Figure 6-23 shows the ocean currents of the world. Ocean currents traveling away from the equator contain warm water. Ocean currents traveling toward the equator contain cool water.

Notice the direction of the current off the southeastern coast of the United States. Off the coast of Florida and the southern states, the current is traveling away from the equator. The current is warm. Because of this current, the climate of Bermuda (an island about 930 km east-southeast of North Carolina) is warmer than locations at the same latitude on the mainland. And at Palm Beach (Florida), the closest point on the mainland to this warm current, the lowest average temperature for the coldest month is 19°C (66°F). But at Miami, which is about 105 km south of Palm Beach, the lowest average temperature for the coldest month is 15.5°C (60°F).

Now look at the ocean current off the west coast of the United States. Off the west coast, the current is traveling toward the equator. This current contains cool water. That is why a city along the southeastern coast of North America can be expected to have warmer temperatures than a city at the same latitude on the west coast.

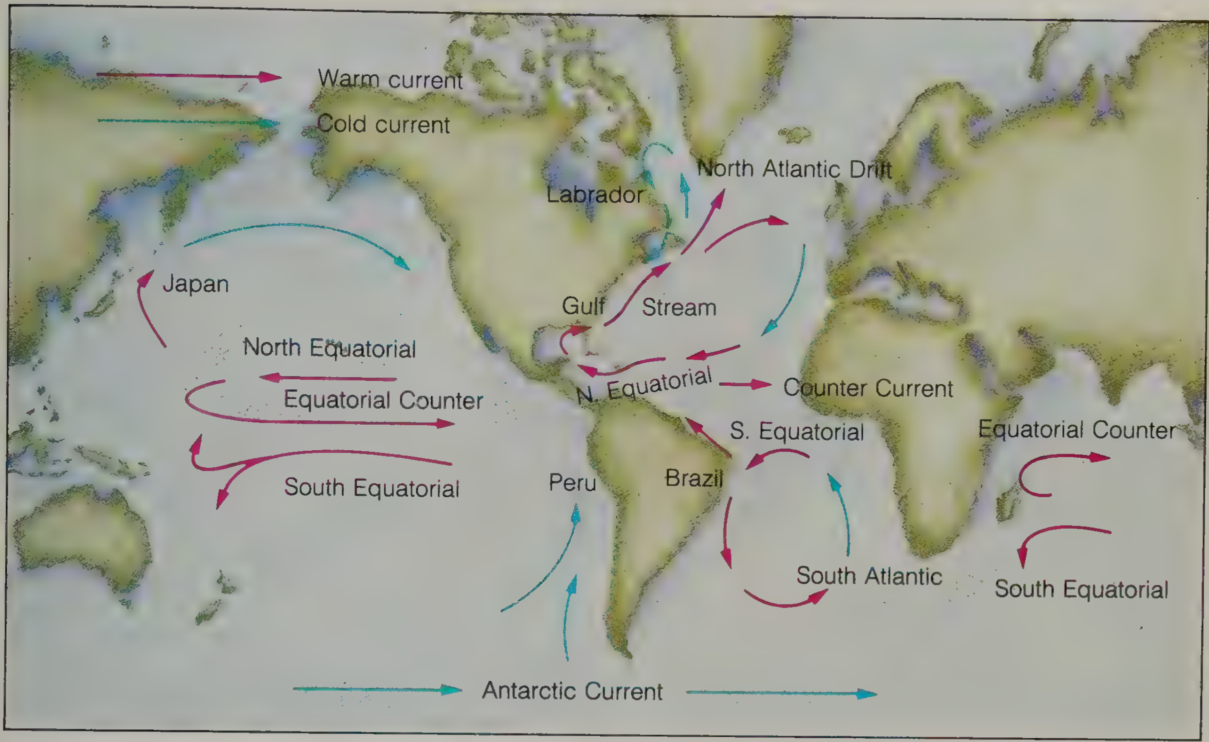


Figure 6-23. Ocean currents flowing away from the equator contain warm water.

Check yourself

1. How does altitude affect climate?
2. How do ocean currents traveling northward from the equator affect temperatures along the coast?

Factors that affect moisture

In general, average amounts of precipitation are affected by nearness to a large body of water. But there are natural factors that affect average amounts of precipitation at a particular location, just as there are natural factors that affect temperature. Two natural factors that affect average amounts of precipitation are prevailing winds and mountain ranges.

Prevailing winds. The Sahara Desert is one of the driest places on the earth. Yet it extends to the Atlantic Ocean. How can an area that borders the ocean be a desert? Look at the belts of prevailing winds shown in Figure 5-17 on page 253. Notice that in some locations the prevailing winds carry air from over water to land. In other cases, the prevailing winds carry air from the land to water.

Figure 6-24. Near Infni, Morocco, the Sahara meets the Atlantic Ocean. Why doesn't the part of the Sahara Desert that borders the Atlantic have a moist marine climate?

Air blowing from over the water to the land will have a high moisture content. Air blowing from the land to water will have a much lower moisture content. The air moving across the Sahara Desert has come across the continent. As it moved across the continent, it lost what little moisture it had. The prevailing wind direction is more important in determining whether a climate is humid or dry than its closeness to the ocean.

When you picture a desert, your first thought is probably endless expanses of sand. Actually a **desert** is defined as an area where the total annual amount of precipitation is less than 10 in (254 mm). Some deserts extend out over oceans! There is plenty of water present, but there is hardly any precipitation.

It is not a coincidence that most of the earth's deserts lie along the Tropic of Cancer or the Tropic of Capricorn. These two areas, at 23½° N and S latitude, are regions of descending air. This air heats up as it sinks. Warming air produces very little precipitation. Even if the air is descending over the ocean, there will be very little precipitation.

Mountain ranges. Mountain ranges also affect the amount of precipitation that falls at a particular location. The mountain ranges along the west coast of the United States, for example, act as a barrier to moisture that is carried by the prevailing

Careers Climatologist / Air-conditioning Mechanic

Maps and graphs are useful to climatologists, who study long-term weather conditions.

Climatologist Climatologists (klī′-muh-TOL′-uh-jists) are meteorologists, but they do not predict tomorrow's weather. They work with yearly and seasonal patterns of temperature, rainfall, and other weather conditions. They describe the climate of an area and identify the causes of its typical weather.

Climatologists also study changes in weather patterns, and they try to find out why these changes occur. Events on earth, such as volcanic eruptions, and events in space, such as storms on the sun, affect our weather. Climatologists investigate all these things.

Climatologists use the information from their research to predict future weather patterns. This information helps people plan food production, design buildings, and develop heating and cooling systems.

Most climatologists have a graduate degree in meteorology. The federal government is the main employer of climatologists.

Air-conditioning mechanics are responsible for the installation and maintenance of air-conditioning equipment.

Air-conditioning Mechanic A central air-conditioning system has several different components. One machine cleans the air. Other machines control temperature and humidity. Ducts, or pipes, circulate the air.

These systems are installed and serviced by skilled air-conditioning mechanics. To install a system, the mechanics first read blueprints and instructions. Then they use a variety of tools to assemble the components. If a system breaks down, the mechanics find the problem and make the necessary repairs. They also work on heating and refrigeration equipment.

Many air-conditioning mechanics learn their skills through on-the-job training. They are hired as helpers or apprentices and trained for about four years. Others study air-conditioning and refrigeration in high schools, vocational schools, or junior colleges.

If you enjoy figuring out how machines work, and if you are interested in working with heavy equipment, you might want to consider this career. Your high school preparation should include courses in physics, math, and mechanical drawing.

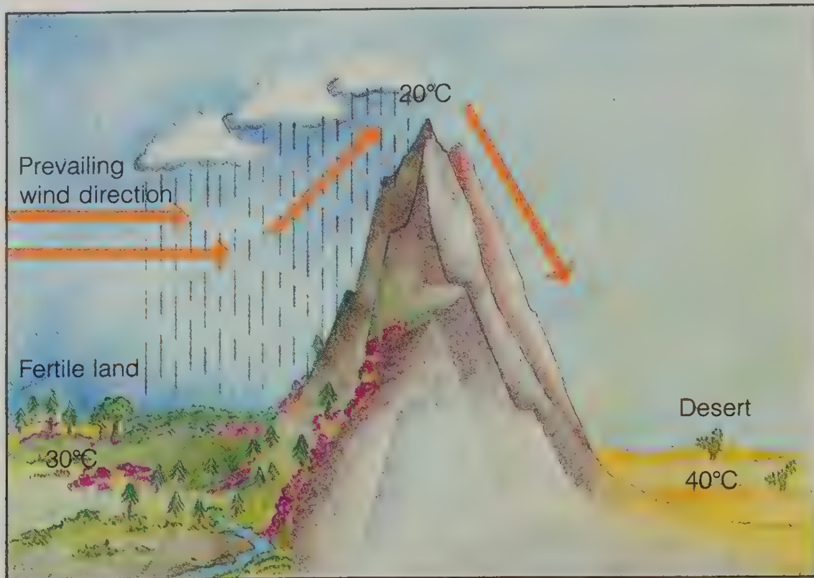


Figure 6-25. How can mountains cause deserts?

Why does precipitation occur as air rises?

westerly winds that carry moisture from out over the Pacific Ocean. As shown in Figure 6-25, mountains cause air to rise. As air rises, it cools and most of its moisture condenses, falling to the surface of the earth as precipitation. Cities and towns on the windward side of the mountains, between the Pacific Ocean and the coastal ranges of mountains, receive high annual amounts of precipitation.

On the side of the mountains that is sheltered from the wind, called the leeward side, conditions are very different. By the time the westerly winds reach the top of the mountains on the windward side, they have lost most of their moisture in the form of precipitation. Then, as this air descends on the leeward side, it warms up rapidly (1°C for every 100 m of elevation it loses). This temperature change is an adiabatic change, caused solely by the expansion or compression of a material.

The air that descends on the leeward side of the mountains quickly loses through evaporation whatever moisture it contained. The mountains have, in effect, produced a rain shadow, blocking rain from reaching the area on the leeward side of the mountains. If these prevailing winds continue throughout the year, a **rain-shadow desert** is produced.

Check yourself

1. How is it possible to have a desert over the ocean?
2. On which side of a mountain range would you expect to find the drier climate? Why?

Our Science Heritage

Did Glaciers Really Cross the Sahara?

If asked to compare the climates of the Sahara Desert and Antarctica, you'd probably have little difficulty. The climate of the Sahara is hot and arid. Antarctica has a polar climate and is characterized by below-freezing temperatures and a permanent cover of ice and snow.

Descriptions of present-day climates are based on direct and indirect observations. Weather data for an area is gathered over a period of time. The data is studied. Patterns are inferred.

It is also possible to infer what climates were like long before people left written records of weather data. The earth's rocks date back billions of years and contain evidence of what the earth's climates were like in the past. Distinctive grooves in rock surfaces in the Sahara, for example, indicate that glaciers once traveled across that area. And coal deposits and fossil palm leaves in Antarctica indicate that that land surface once experienced a warm and humid climate.

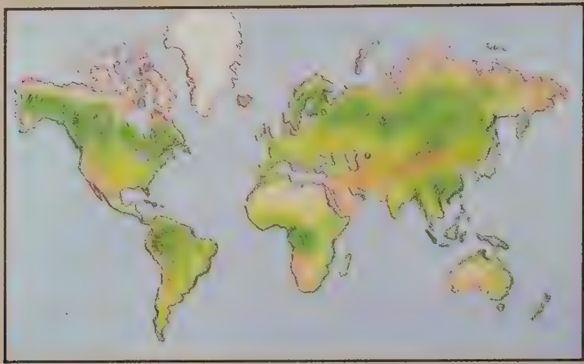
What are some of the evidences? Coral and carbonate rocks like limestone and dolomite indicate that the area was probably once covered by tropical seas (warmer than 18°C and 25 m to 60 m in depth). Widespread salt deposits are evidence of a former climate that was arid and relatively warm. Coal deposits indicate former low-lying swamps of luxuriant vegetation and a warm, moist climate. Fossil forms of land and sea organisms also tell much about former conditions at a particular location.

Additional evidence of climate changes is obtained from fossils in sea cores (100 million years), the oxygen content of ice in ice cores (120 thousand years), and the rings of a bristle-cone pine (4 thousand years).

Climate graphs

A **climate graph** provides a picture of the climate conditions at a particular location during the year. It depicts the average monthly temperature and precipitation conditions. Climate graphs are helpful for comparing the climates of different cities. From climate graphs, you can tell at a glance which cities have hot summers or cold winters. You can also tell which cities have dry or humid climates.

Activity Plotting a Climate Graph



Materials

data table on this page
graph paper
world map

Purpose

To compare climates at three different locations.

What to Do

1. The data table on this page contains information about the climates of three different locations. Using the same format as the climate graphs on the facing page, plot the monthly temperatures and amounts of precipitation for each location.
2. The three locations represented are Memphis, Tennessee; Jacobabad, Pakistan; and Buenos Aires, Argentina. Match each to its respective climate graph. Find each location on a world map.

Questions

1. From your climate graphs, how would you describe the climate of each location? How would you compare them?
2. How can you tell quickly from a climate graph if a location is in the Southern Hemisphere?

Conclusion

What can you tell about an unnamed location from a climate graph?

Data Table

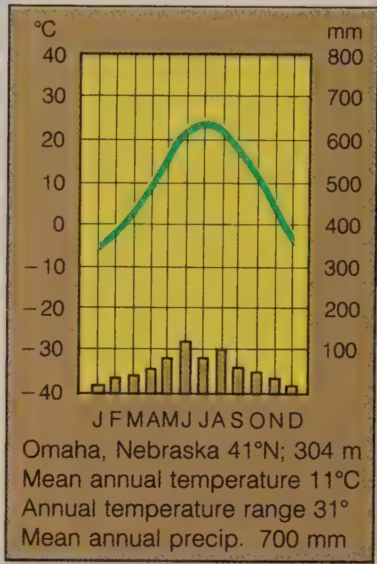
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
LOCATION A														
Average Temp. (°C)	24	23	21	17	14	11	10	12	14	16	20	22	17	average
Total Precip. (mm)	104	82	122	90	79	68	61	68	80	100	90	83	1027	total
LOCATION B														
Average Temp. (°C)	15	18	24	30	35	37	35	34	32	28	22	17	27	average
Total Precip. (mm)	8	8	7	2	4	6	37	22	1	0	1	3	99	total
LOCATION C														
Average Temp. (°C)	6	7	11	17	22	26	28	27	24	18	11	7	17	average
Total Precip. (mm)	148	116	124	117	102	92	87	67	71	73	106	119	1223	total

Look at the climate graph for Omaha, Nebraska, in Figure 6-26. The solid line connects the average monthly temperatures. In April, for example, the average temperature in Omaha is about 10°C. In September, the average temperature is about 18°C.

The solid bars show the average total amount of precipitation for each month of the year. On the average, about 70 mm of precipitation falls in Omaha during the month of April. In November, the average is about 30 mm. These figures are only averages. One year, the amount of precipitation may be more. The next year, it could be less.

Now look at the climate graph for Paris, France. There the average temperatures for April and September are about 10°C and 16°C. The fall and spring temperatures are almost the same as for Omaha. But the summer and winter temperatures are very different. Average winter temperatures are colder in Omaha. In January, the average temperature is about 3°C in Paris, but it is −4°C in Omaha. Average summer temperatures are hotter in Omaha. In July, the average temperature in Paris is about 18°C. In Omaha, it is about 24°C. Though the average temperature for the year is the same for both cities (11°C), the temperature range is much greater for Omaha.

What do the climate graphs tell you about average amounts of precipitation in Omaha and Paris? Over a whole year, the total amount is fairly similar for both cities. Paris receives an average of 585 mm of precipitation, and Omaha receives an average of 700 mm. But there is a major difference in the patterns of precipitation between the two cities. In Paris, the amount of precipitation is almost the same from month to month throughout the year. But in Omaha, the amount of precipitation is high during the summer but low during the winter.



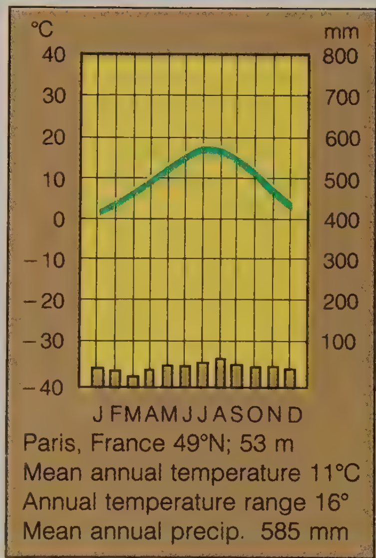


Figure 6-26. On these climate graphs, the line toward the top plots average monthly temperatures. The bars at the bottom indicate average monthly amounts of precipitation.

Check yourself

1. What do climate graphs show?
2. How are average monthly temperatures indicated on a climate graph? How are amounts of precipitation indicated?
3. Why is it important to consider the monthly patterns on a climate graph rather than just the totals?

Activity Observing Effects of Climate Changes

Materials

2 or 3 large flowerpots, or other containers suitable for growing plants

6 or more small plants of one kind of local vegetation

ruler

Purpose

To see how plants of the same kind are affected by different climates

What to Do

1. Prepare the flowerpots with the plants in them. All plants should be of the same kind (for example, all the same variety of common weed or whatever other kind of local vegetation you choose). Also, each pot should contain the same number of plants.
2. If you are transplanting your plants from the ground outside, you will need to give the plants about a week to get over the shock of transplanting and to adjust to their new surroundings. Remove any that fail to adjust.
3. If you cannot obtain living plants from outside, you can obtain plants from seeds. Choose the seeds of plants that are normally found in your area. Also choose seeds that will produce seedlings easy to recognize.
4. When your plants are ready for the activity, measure and record the heights of the plants in each pot. Label one flowerpot Climate 1. Label the other flowerpot Climate 2.
5. Climate 1 will be the existing local climate. Climate 2 (and Climate 3, if you wish) will be the artificial climate conditions you create.
6. Decide how you are going to make Climate 2 different from Climate 1. Any change in temperature conditions, moisture conditions, or both can be used. If the temperature is much hotter or colder outdoors, the Climate 2 plants can be left indoors on a windowsill where they will receive sunlight. The Climate 1 plants can be left outdoors. Another possibility would be to give the Climate 2 plants a certain amount of water twice a week. A third set of plants, Climate 3 plants, might be given the same amount of water but only once a week or once every two weeks.
7. Whatever differing climate conditions you choose, they should represent different climates. Before you begin the activity, write a brief description of what the temperature and moisture conditions will be for each climate and how you plan to see that those conditions are maintained.
8. Place each set of plants in its respective climate. Once a week, for at least three weeks, measure and record the heights of the plants in each flowerpot. For each week's readings, also calculate the average height of the plants in each pot.
9. You may wish to investigate the effect of climate changes on more than one type of plant. If the flowerpots are large enough, you could grow samples of both plant types in the same pot. Otherwise, you could use more than one pot for each climate. In either case, take separate average heights for each plant type.

Questions

1. What plant type(s) did you use?
2. What type of climate did each set of plants grow under?
3. How did the growth of the plants compare?
4. Why use more than one plant in each pot? Why compare the average heights rather than the heights of individual plants?
5. In which climate did your plants grow better?

Conclusion

What do you think would have happened if you had used different plants of the same type? if you had used different plant types?

Section 3 Review Chapter 6

Check Your Vocabulary

adiabatic change	marine climate
climate	polar climate
climate graph	rain-shadow desert
continental climate	temperate climate
desert	tropical climate

Match each term above with the numbered phrase that best describes it.

1. The weather patterns that occur in one place over a period of a year or longer; determined primarily by average amounts of precipitation and average temperatures
2. A climate influenced mainly by tropical air masses; characterized by the warmest temperatures
3. A climate influenced mainly by polar air masses; characterized by cold temperatures
4. A climate influenced mainly by maritime air masses; characterized by abundant precipitation; also called an oceanic climate
5. A climate influenced by both polar and tropical air masses; characterized by moderate temperatures
6. A climate influenced mainly by continental air masses; characterized by dry air
7. A change in temperature that occurs solely because of the expansion or compression of a material and not because of any heat exchange between different materials
8. Any area where the total amount of precipitation is less than 10 in (254 mm) per year
9. A desert caused by a mountain range that prevents prevailing winds from bringing moisture to an area
10. A graph that indicates average monthly temperature and precipitation conditions for twelve months at a particular location

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. ? is the atmospheric conditions at a particular location at a particular moment in time.
   a) Weather
   b) Climate
   c) The average temperature
   d) Average rainfall
2. Any climate of the world can be classified according to ?.
   a) wet and dry
   b) hot and cold
   c) temperature and moisture
   d) polar and tropical
3. As air rises, it ?.
   a) compresses and warms
   b) compresses and cools
   c) expands and warms
   d) expands and cools
4. Most of the earth's deserts are located ?.
   a) along the Tropics of Cancer and Capricorn
   b) along the windward side of mountains
   c) near warm ocean currents
   d) at the same latitude as Death Valley

Check Your Understanding

1. Compare weather and climate. How are they similar? How do they differ?
2. Explain how and why latitude affects climate.
3. Explain how and why altitude affects climate.
4. Explain what happens to the moisture content of descending air. What causes this to happen?
5. How do ocean currents affect the climates of cities on the east and west coasts of the United States? Why does this happen?

Chapter 6 Review

Concept Summary

An **air mass** is a large body of air that moves as a unit and that has more or less uniform characteristics throughout.

- ☐ Air masses are named by the kinds of locations over which they form.
- ☐ Though generally uniform throughout, some variation in temperature, atmospheric pressure, and moisture content occurs within an air mass because of differences among local conditions.
- ☐ Air masses are responsible for the weather conditions at a particular location.

A **weather front** is the boundary between two air masses and often produces a change in the weather.

- ☐ Differing cloud types and precipitation patterns are associated with cold fronts and warm fronts.

A **station model** is a clear and simple way of recording weather conditions at a particular weather station.

- ☐ Information from station models for different locations is fed into computerized data banks and is used to obtain larger weather patterns.

A **weather map** is a representation of weather conditions over an area of the earth's surface.

- ☐ A weather map incorporates information from radar, satellites, and weather balloons.
- ☐ Patterns observed on weather maps for successive days are useful in predicting the weather.

Climate is the average weather conditions, primarily moisture and air temperature, that occur in one place over a year or longer.

- ☐ Climates are distinguished on the basis of average moisture and average temperatures.
- ☐ Average temperatures are affected by latitude, altitude, and ocean currents.
- ☐ Average moisture is affected by prevailing winds and nearness to large bodies of water.

Putting It All Together

1. Describe the following air masses: c, m, P, T. For each, give the name, tell where it forms, and give a general characteristic.
2. Draw a diagram of a cold front, a warm front, and an occluded front. Indicate the direction of movement of each front.
3. Would you expect heavier precipitation along a cold front or warm front? Why?
4. What is a station model? What kinds of information are given on a station model? In what form is the information expressed?
5. Explain why weather predictions are often expressed as probabilities.
6. Describe some of the similarities and differences between hurricanes and tornadoes.
7. Describe effects of advance warning in weather forecasting.
8. Relate the major climates to location and to air masses.
9. How do prevailing winds affect climate?
10. Explain the relationship between deserts and descending air.

Apply Your Knowledge

1. In what general direction would you expect a cold air mass to move? Why?
2. It is raining in a nearby city. How would you tell whether it might rain where you live?
3. Construct a station model that indicates that the sky is cloudy, the air temperature is 80°F, the dew-point temperature is 48°F, the atmospheric pressure is 1015.9 mb, there is no precipitation, and the wind is blowing from the southeast at 15 knots per hour.
4. Why is it helpful for station models to use the same symbols and to indicate the same kinds of information in the same positions?
5. Explain how ice-covered polar regions can have very dry climates.

Find Out on Your Own

1. List factors that influence the climate in your area. How does each affect the climate?
2. How does the climate of your area affect the following: what is worn; what is grown; the type of construction used in buildings; energy consumption?
3. What cities or towns in other parts of the world have climates similar to yours? How do those cities or towns compare with yours in what is worn, what is grown, the type of construction used in buildings, and in energy consumption? What might explain any differences?
4. How does the climate of your area affect the type and amount of industry found in your area? What aspects of your climate might attract industrial growth? What aspects might act as a deterrent? Explain.

Reading Further

Gribbin, John. *Weather Force: Climate and Its Impact on Our World.* New York: G. P. Putnam's Sons, 1979.

Detailed data on many aspects of weather, storms, and climates. Exciting photographs. A book to browse through rather than read from cover to cover. A handy source for much out-of-the-ordinary reference-type information.

Hays, Dr. James D. *Our Changing Climate.* New York: Atheneum; 1977.

A clear and mature presentation of the earth's climates. Smooth-flowing text that interweaves data, theory, the past, present, and future.

Lambert, David. *Weather.* New York: Watts, 1983.

A well-written, informative account of most weather phenomena. Good index and illustrations.

Ross, Frank, Jr. *Storms and Man.* New York: Lothrop, Lee & Shepard Co., 1970.

A clear, informative, chapter-by-chapter presentation of different kinds of storms. Scientific information is combined with photographs and historical accounts of destructive storms of the past. Many black and white photographs.

Rubin, Louis D., with Hiram J. Herbert. *Forecasting the Weather.* New York: Franklin Watts, Inc., 1970.

Clear identification and presentation of the different elements that influence the weather. Includes photographs of various cloud sequences with explanatory text that tells what kind of weather each sequence signals.

Witty, Margot and Ken. *A Day in the Life of a Meteorologist.* Mahwah, NJ: Troll, 1981.

Presents a typical day in the life of a weather forecaster. Explains how weather information is gathered from satellite pictures, weather maps, and related equipment.

Science Issues of Today   Preventing Disasters from Sudden Weather Changes

Meteorologists are able to predict and track certain types of storms by using data from remote sensing devices from satellites, from land stations, and from ocean buoys. Hurricanes can be tracked and coastal residents are often given enough warning so that they can take steps to protect themselves.

However, certain types of weather conditions are difficult, if not impossible, to accurately predict. In midsummer, 1976, twelve inches of rain fell in five hours in north central Colorado. The Big Thompson River increased its flow drastically, and the ensuing erosion and flooding killed nearly 140 people and destroyed about 250 structures.

In June, 1982, a sudden storm developed winds over 70 knots, capsized two sailboats, and destroyed a large fishing ship and its entire crew. In this case, the atmospheric pressure dropped rapidly over a short period of time. This type of pressure drop is not usually predictable with current sensing devices and computer analysis.

In May, 1985, tornadoes ripped through parts of eastern Ohio and western Pennsylvania. People were killed and many houses and businesses were destroyed.

Airplanes have experienced sudden sideways or downward bursts of wind that are very dangerous, especially during landing or takeoff. In August, 1985, at a Texas airport, a large airliner crashed while landing because of this type of wind shear.

What can be done to predict sudden shifts in wind and weather? Each of the wind or storm conditions mentioned above is thought to be caused by different conditions. Each presents its own difficulties in prediction and monitoring. These storms arise so rapidly that long-term prediction is impossible.

Detecting unusual weather conditions that may affect flying is an important concern for meteorologists.

However, short-term prediction and warning may be possible. Often, the judgment of experienced meteorologists has been all that prevented even greater disaster from rapid weather changes. One of the technologic tools that a meteorologist can use is called Doppler radar (see pages 151 and 153 for a discussion of the Doppler effect). This radar device can accurately measure changes in wind that could forewarn of certain problems like wind shear and tornadoes; but the warning time is still very short, and it would require an almost impossibly large deployment of radar units to cover all airfields and tornado-prone areas.

Scientists are studying these weather phenomena and the environmental conditions that precede them. They may find that, even with improved prediction techniques, the warning time before a disastrous wind or storm may still be very small. We may then find that the best defense is to understand the intensity of sudden bad weather, and build our houses, buildings, and roads accordingly.

Water in Motion

Unit 4

Water distinguishes the earth from other planets in the solar system. Water provides the moisture needed by the cells of living organisms. Water provides an environment in which many of the earth's organisms live. Water—moving water and the alternate freezing and thawing of water—is responsible for many of the beautiful formations of the earth's landscapes.

Modern technology has enabled scientists to extend their observations to objects never seen before—the tiniest particles of matter; objects on the surface of the moon, Mars, and other planets; organisms deep below the surface of the ocean, where life occurs in total darkness. Like outer space and inner space, the earth's oceans offer exciting frontiers for scientific exploration, investigation, discovery, and progress.

Chapter 7

The Earth's Fresh Water

Section 1

Water on the Ground

Rain may be inconvenient. It may, for instance, spoil a picnic or force the cancellation of a game. But rain is a basic earth process and part of the earth's water cycle.

The earth's fresh water cycles between the earth's surface and the earth's atmosphere. Water leaves the earth's surface through evaporation and returns through precipitation.

On the earth's surface, some of the water flows in streams and rivers. Some collects in lakes and ponds. Some collects in glaciers and icebergs.

Section 2

Water in the Ground

Part of the water that returns to the earth as precipitation flows across the earth's surface, but part of it soaks down into the earth's surface and becomes part of the earth's underground water supply.

Water comes out of the ground, sometimes in startling ways or in unexpected places. And stored deep beneath the earth's surface, meltwater from Ice Age glaciers remains cool and clear and pure.

The earth's brooks and streams carry fresh water downhill toward the sea. Brooks and streams can be pleasant-sounding and provide a habitat for many plants and animals. If there is a stream near your home, where does the water in the stream come from, and into what larger body of water does the stream flow?

Water on the Ground Section 1

Section 1 of Chapter 7 is divided into four parts:

Water recycles

Water collects on the ground

Water runs off the ground

Water leaves the earth's surface

Figure 7-1. In the picture, you can see liquid water (the ocean and the clouds). You can see solid water (the iceberg). But you cannot see the water in its third form, water vapor in the atmosphere, because water vapor is an invisible gas.

Only 3% of all the earth's water is fresh water. The other 97% is stored in the earth's oceans as salt water. Where does the earth's fresh water come from? And where does it go?

Water recycles

Water is a very unusual earth material because it is found in all three forms of matter. Water is found as a liquid in the oceans, in other bodies of water, in porous rocks and soil, and in the atmosphere (water droplets in clouds). Water is found as a solid in the oceans (icebergs), on the land (glaciers and icecaps), on frozen bodies of water (ice), and in the atmosphere (ice crystals in clouds). And water is found as a gas in the atmosphere. Table 6-1 shows the distribution (in volume) of water on the earth.

Distribution of Water on the Earth			
Location	Form	Volume	Percent of Total Volume
oceans	liquid	1 322 000 000 km^3	97.2%
icecaps and glaciers	solid	29 200 000 km^3	2.15%
on or under land	liquid	8 637 000 km^3	0.635%
atmosphere	solid, liquid, gas	13 000 km^3	0.001%

Table 7-1. How much of the earth's water is found in the oceans?

Not only is water found in all three forms of matter. It also changes back and forth from one form to another. At 0°C, water **freezes,** changing from a liquid to a solid. At 100°C, water boils. When air is cooled to a low enough temperature, the water vapor in the air **condenses,** changing from a gas to a liquid or even to a solid. Between 0°C and 100°C, water **evaporates,** changing from a liquid to a gas.

At what temperature does water freeze?

According to present scientific estimates, the earth formed as a planet about 4.6 billion years ago. During all the years between then and now, water has been moving continuously into and out of the atmosphere. Water vapor enters the atmo-

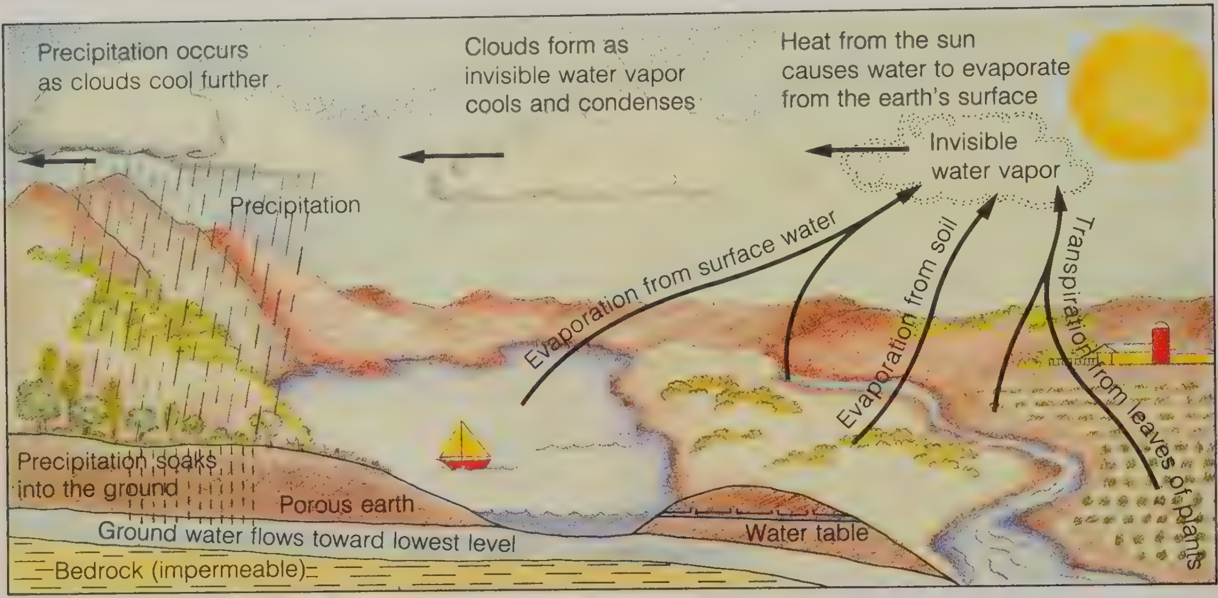


Figure 7-2. The earth's water is recycled in a combination of processes that make up the water cycle.

sphere from the oceans. Each year about 80 000 cubic miles of water evaporate from the surface of the oceans. Water vapor also enters the atmosphere from the leaves of living plants. Water returns from the atmosphere as a liquid or solid, condensing and falling back to earth. This recycling process whereby water enters the atmosphere by evaporation and transpiration, then condenses, and then returns to the earth's surface as precipitation is called the **water cycle** or the hydrologic cycle.

Much of the precipitation that returns to earth falls back into the oceans. But what happens to the water that falls on the land areas of the earth? Where does that water go? Some of it evaporates back into the atmosphere. Some of it soaks into the ground and becomes part of the underground water supply. Part of it stays on the surface of the earth, and part of it runs off.

Library research

Edmund Halley is responsible for advancing our understanding of the water cycle. Find out more about Edmund Halley.

Check yourself

1. Where on the earth is water found in each of the three states of matter?
2. Explain the changes that take place in the water cycle.

Our Science Heritage

Water and Ancient Civilizations

People cannot live without fresh water. Their body cells and body processes depend on a continual supply of fresh water. Also, the food that people eat requires water to grow.

Civilizations could not develop without the invention of farming. With farming, people could stay in one place and raise their own food rather than relocate depending on the availability of natural foods.

Evidence indicates that people in the Middle East began raising grain, goats, and sheep about 11 000 years ago. Crops were raised and animals domesticated about 9500 years ago in Southeast Asia and about 8500 years ago in what is now Mexico.

About 5000 years ago, four major civilizations arose. Each of those civilizations developed in a river valley that contained fertile soil for farming and fresh water for irrigation and for use by people. The four river valleys are the Nile (in present-day Egypt), the Tigris and the Euphrates (in present-day Iraq), the Indus (in present-day Pakistan), and the Hwang Ho, or Yellow River (located in present-day China).

Scientists who study the past feel that there is a connection between the rise and fall of civilizations and the way they used their land and other natural resources. In the case of the Sumerians, who lived in the valley between the Tigris and the Euphrates Rivers, there is evidence that they destroyed their farmlands by poor irrigation practices.

They increased the salt content of the soil to a point where crops could no longer be raised (a problem that still occurs in areas that water their crops by irrigation).

Figure 7-3. Margerie Glacier flows downhill until it meets the sea at Glacier Bay, Alaska.

Where is most of the earth's fresh water supply stored?

Water collects on the ground

Water can return to the earth as rain, a liquid, or as snow, a solid. When the water returns in the form of snow, the snow may collect and pile up to great depths. Increasing pressure on the bottom layers of snow causes that snow to change to ice. Most of the earth's fresh water supply is stored in glaciers and other forms of ice.

A **glacier** is a moving mass of ice and snow. Glaciers flow downhill and out from their center. Glaciers usually move very slowly, gouging and reshaping the land as they go.

In order for glaciers to exist, more snow must fall than melts each year. Most of the glaciers and ice sheets are located near the North Pole and the South Pole where the energy from the sun, even in summer, is not strong enough to melt all the ice and snow.

Water collects in lakes, ponds, and swamps. A **lake** forms when water collects in a hole or depression in the earth's surface. The Great Lakes, pictured in Figure 7-4, are the largest body of fresh water on earth. They are thought to

Figure 7-4. The Great Lakes form the largest body of fresh water on the earth. It is estimated that together the Great Lakes contain 22 800 cubic kilometers of fresh water, which is almost twice as much as all the water contained in the earth's atmosphere.

have been formed about 250 000 years ago, when a glacier dug the lake beds out of the rock surface. The rock and soil that were scooped out of the hollow formed natural dams. Somewhere between 11 000 and 15 000 years ago, the southern part of the glacier melted. Water from the melting glacier filled the huge hollows and formed the Great Lakes.

Many lakes of the world were formed by glaciers. Some lakes form when water fills the craters of inactive volcanoes. Crater

Figure 7-5. Volcanic lakes can be very deep. Crater Lake, which is formed in the crater of an inactive volcano in southwestern Oregon, is about 610 meters deep.

Figure 7-6. Bald cypress trees grow in this water-filled swamp near Wilmington, North Carolina.

Lake, pictured in Figure 7-5, is an example of a lake that formed within the collapsed crater of an inactive volcano. *Reservoirs* are lakes made by people. They are usually formed by damming a river. F. D. Roosevelt Lake is the reservoir behind the Grand Coulee Dam (Figure 2-28).

What are swamps?

Some surface water collects in ponds as well as lakes. A **pond** is a body of water that is smaller and shallower than a lake. Ponds and lakes which are filled with water and vegetation are called **swamps.** The English word *swamp* comes from a Greek word that means sponge. If you've ever seen a swamp, you know from direct observation how well the name *swamp* fits these low-lying water-soaked marshes and bogs. Swamps provide a home for many varieties of plants and animals.

Check yourself

Name four places where fresh water collects on the earth. Give a brief description of each.

Water runs off the ground

A large amount of liquid water that falls to the earth has no place to collect. Much of this water flows directly off the surface and is known as **runoff.**

Runoff occurs in one of two ways: sheet runoff and streams. **Sheet runoff** has no channels to direct its flow. It runs off the surface as broad flat sheets of water. **Streams** are runoff that flows in channels between banks of soil, rock, or other material. The banks of the stream contain the flowing water and give it direction.

What are two ways in which runoff occurs?

When water falls onto a mountain ridge, for example, or when snow melts on the ridge, some water will run off on one side of the ridge and some water will run off on the other. The highest land that separates the direction in which water will run off is called a **divide.** (See Figure 7-7.) A divide causes the water to run off in one direction or the other, depending on which side of the divide the water falls on.

The mightiest river systems in the world begin as small flows of water that feed into little stream channels. These little stream channels flow into larger stream channels until they eventually form a river. Streams and small rivers that empty into one large river system are called **tributaries.** Eventually the large main river empties into the sea.

What are the streams that empty into a large river system called?

A river will need a much wider channel than a stream to carry all the water that is emptying into it from its tributaries. The distance between the banks of the Mississippi River, for example, varies from 0.3 m near its beginning to over 1500 m near its end.

All the area of land that drains into a river, along with its

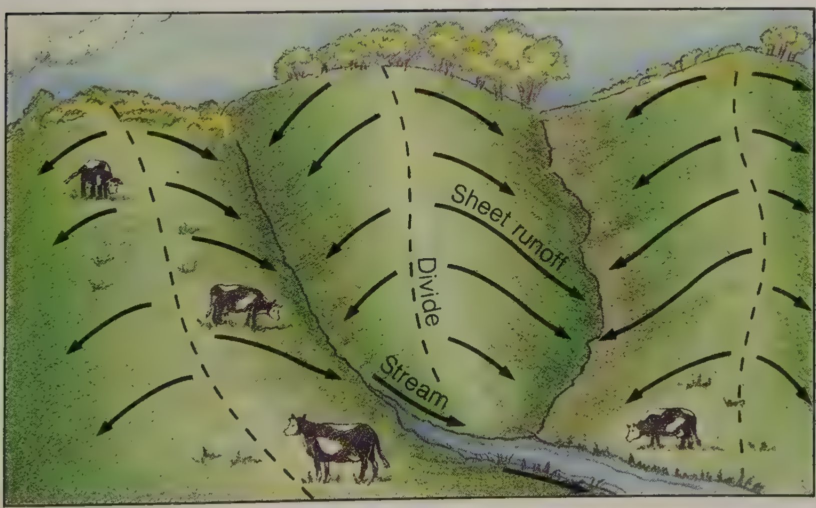


Figure 7-7. What is a divide?

Activity Comparing Rainfall and Stream Discharge

Materials

data table
graph paper
black pencil
colored pencil

Purpose

To graph an amount of rainfall and the resulting amount of stream discharge.

What to Do

1. On a graph, plot the data from the data table. The vertical axis on the left side will show the amount of rainfall in cm/hour. The vertical axis on the right side will show the volume of discharge in m^3/second. Discharge is the amount of stream water that flows past a stream gauging station each second. The horizontal axis will show the time (from 12 noon to 9:00 p.m.). You will actually be plotting two graphs—one for rainfall and one for stream discharge.
2. Using a black pencil, plot the amount of rainfall recorded for each of the times indicated on the horizontal axis. Connect the plots with a line in black pencil.
3. Using a colored pencil and the vertical axis on the right side, plot the stream discharge for each of the times indicated. Connect the plots with a line in the same color.

Questions

1. About how many hours after the heaviest rainfall was the stream discharge the greatest? What might explain the time difference?
2. How do the two graphs compare in height? Which is lower? What might explain this difference?
3. How do the two graphs compare in shape? Which has more gradual curves? What does this indicate? What might explain this difference?

Conclusion

How does the amount of rainfall affect the amount of stream discharge?

Data Table

Time	Amount of Rainfall in cm/hour	Stream Discharge in m^3/second	Time	Amount of Rainfall in cm/hour	Stream Discharge in m^3/second
12 noon	0	100	5:00 p.m.	0.2	3000
1:00 p.m.	2.6	200	6:00 p.m.	0	2000
2:00 p.m.	4.7	500	7:00 p.m.	0	1000
3:00 p.m.	4.8	1100	8:00 p.m.	0	500
4:00 p.m.	2.0	2000	9:00 p.m.	0	500
Total				14.3 cm	10 900 m^3

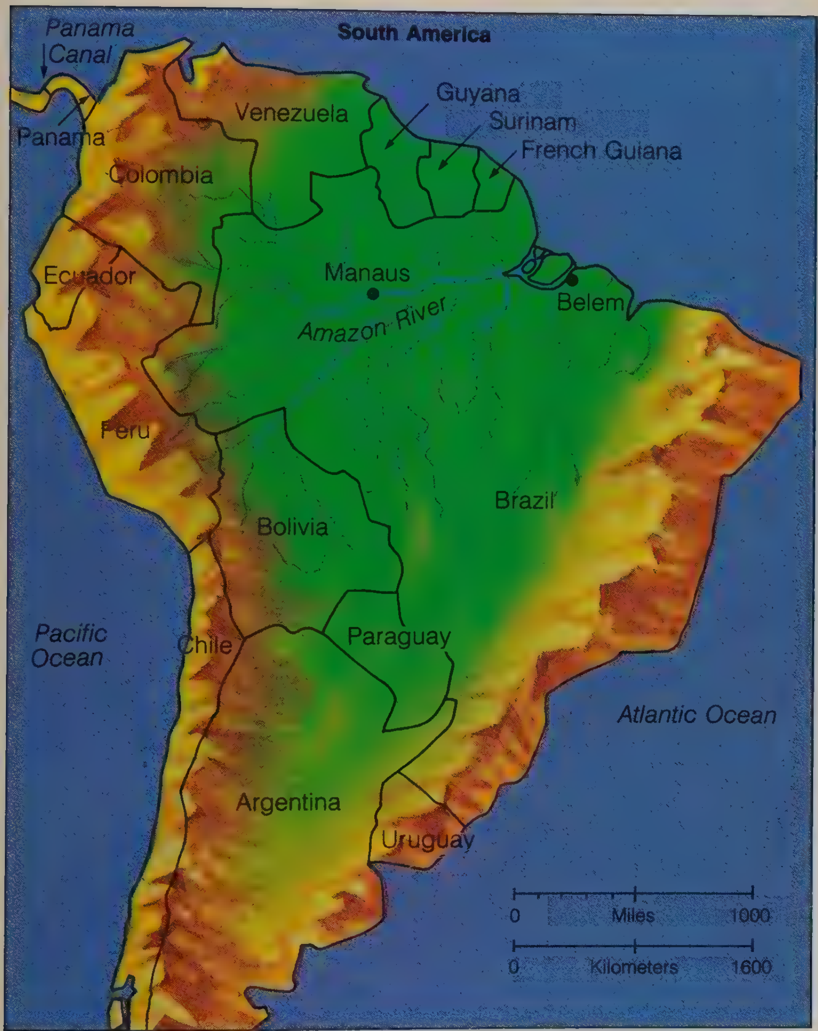


Figure 7-8. Most of Brazil serves as a source of runoff for the Amazon River. What is the name of the entire area that serves as a source of runoff for a river system?

system of streams and other tributaries, is called a **watershed.** Figure 7-8 shows the watershed for the Amazon River, which is over 6000 km long. As you can see from the map, most of Brazil serves as a watershed for the Amazon.

Check yourself

1. Compare streams and sheet runoff. How are they similar? How are they different?
2. Describe a watershed in terms of boundaries and function.

Water leaves the earth's surface

Water rises from the earth as a gas, or vapor. As you read these words, water is evaporating from many of the surfaces around you—and on you!

Water evaporates from the surface of your skin. The human body is constantly getting rid of moisture through small openings, called pores, in the skin. But this moisture, which is called perspiration, is noticeable only when it builds up on the skin.

Figure 7-9. Through a certain process, an acre of growing corn can cause 1.8 million liters of water to enter the atmosphere as water vapor in a single growing season. What is this process called?

Most of the time, this moisture is removed from the skin by evaporation.

As green plants make food, they give off water vapor to the atmosphere through small openings in their leaves. This process in plants is called **transpiration** (tran′-spuh-RAY′-shun). It is estimated that a typical acre of growing corn can, through transpiration, cause 1.8 million liters of water to enter the atmosphere as water vapor in a single growing season. (For some trees, you can double the amount given for the growing corn.) Since growing trees and plants use sunlight to make food and since sunlight is strongest in the summertime, the amount of water that enters the atmosphere through transpiration is greatest in the summer.

Water evaporates from the surface of the earth, sometimes before you even realize it's there. You've probably seen it rain and right after the rain stops the streets and sidewalks are dry. This usually happens when the streets are very hot and the air has a low humidity. A strong wind will also speed the evaporation of water from the surface of the earth back into the atmosphere.

Sometimes the water falling from a cloud evaporates before it reaches the earth. It is not uncommon to see rain falling from a cloud but never reaching the surface of the earth. This can be seen frequently in dry regions such as the southwestern United States.

Water also evaporates from the area just below the surface of soil. After a rain, the soil is moist. But if soil goes for a long time without water, it dries out. Any particles of liquid water in the spaces among the grains of soil evaporate. They change to water vapor and enter the atmosphere. The surface soil is then left without moisture and must wait for the next rainstorm. In a desert area, evaporation from the soil occurs soon after the storm passes. In other areas, evaporation is not so rapid.

Library research

See if you can find out how water was formed on the earth. Also, do other planets have water? If so, which ones. What is the evidence for such conclusions?

Check yourself

1. Describe two ways in which water leaves the surface of the earth.
2. How do heat, low relative humidity, and wind affect the rate at which water evaporates?

Activity Observing Transpiration from a Plant

Materials

potted plant (coleus or geranium works best)

large plastic bag with tie

Purpose

To see evidence of the part transpiration plays in the water cycle.

What to Do

1. Take the plastic bag and place it over the plant. Using the tie, seal the bag tightly around the stem of the plant so that no air gets in. Leave the bag over the plant overnight.
2. The next day, observe the bag around your plant. Describe what you see on a data chart like the one on this page.
3. Remove the plastic bag, put a new bag around the plant, and repeat the experiment.
4. Repeat over several more days if you wish.

Questions

1. What change happened after the plant's first night in the bag? What do you think caused the change?
2. What change(s) happened after the plant's second night in the bag? How does what you observe compare with the results after the first night? Also describe any changes in the plant.

Conclusion

Explain what you observed.

Data Chart

Observation Number	Date	Time	Temperature in °C	Location of Plant	Description of Condensation on Inside of Bag	Changes, if any, in Plant(s)	Mass of Bag and Its Contents
1							
2							
3							
4							
5							

Section 1 Review Chapter 7

Check Your Vocabulary

condense	sheet runoff
divide	stream
evaporate	swamp
freeze	transpiration
glacier	tributaries
lake	water cycle
pond	watershed
runoff	

Match each term above with the numbered phrase that best describes it.

1. To change from a liquid to a solid
2. To change from a gas to a liquid
3. To change from a liquid to a gas
4. The process by which water is continually recycling between the earth's surface and the atmosphere; also called the hydrologic cycle
5. A moving mass of ice and snow
6. A body of water that collects in a hole or depression in the earth's surface; larger and deeper than a pond
7. A low-lying water-soaked marsh or bog that forms when a lake or pond fills with sediment and vegetation
8. Water that flows off the earth's surface
9. Runoff that flows in a channel between banks of soil, rock, or other material
10. A body of water that is smaller and shallower than a lake
11. Water that has no channels to direct its flow as it runs off the earth's surface
12. The highest land that separates the direction in which water will run off the earth's surface
13. Streams and small rivers that empty into one large river system
14. All the land that drains into a river, with its system of streams and other tributaries
15. The process by which green plants, as they make food, give off water vapor through small openings in their leaves

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Water vapor is a ?.
   a) solid c) crystal
   b) liquid d) gas
2. Water freezes at ?.
   a) 100°C c) 20°C
   b) 50°C d) 0°C
3. Most of the earth's fresh water supply is found in the form of ?.
   a) vapor c) ice
   b) liquid d) lakes
4. Water returns to the earth's surface through the process of ?.
   a) transpiration c) boiling
   b) evaporation d) precipitation

Check Your Understanding

1. Describe different places where fresh water is found. For each, tell in what state of matter the water occurs.
2. Trace the steps that occur in the water cycle.
3. Describe four things that can happen to water that falls to the earth's surface.
4. Where would water vapor from transpiration be greater—over a desert or over a forest? Explain.
5. Spring rains and melting snow and ice cause the flooding of a river hundreds of kilometers downstream. Explain why this happens.

Water in the Ground Section 2

Section 2 of Chapter 7 is divided into four parts:

Pore spaces in rock and soil

Water soaks into the ground

Zones of water in the ground

Water comes out of the ground

Figure 7-10. Most of the earth's liquid fresh water is found in the ground. Springs like the one shown in the picture are fed from this underground water supply.

Think of all the freshwater lakes in the world. All together they certainly contain a huge amount of water. Or think of all the fresh water that is contained in the rivers of the world, including the Mississippi and the Nile and the Amazon. Once again, you are thinking of a very large amount of water.

Would you say that most of the earth's liquid fresh water is found in its lakes or in its rivers? Or would you say that most of the earth's liquid fresh water is found neither in lakes nor in rivers, but in a third place? If you chose a third place, you would be correct. Most of the earth's liquid fresh water is found in the ground. In fact, there is fifty times more liquid fresh water below ground than there is in all the lakes, rivers, and streams on the earth's surface.

How does all this water get into the ground? Does it stay in one place once it gets under the ground? Does it ever come back out of the ground? If so, what makes it do this?

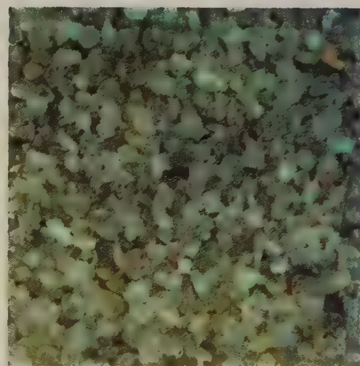


Figure 7-11. Spaces enable water to pass through sand.

Pore spaces in rock and soil

Water can soak into or flow into a material only when there are openings or spaces in the material and when the spaces are not already filled with water. The earth's land surface is made up of different materials. In some places, it is covered with soil. In other places, it is covered with sand or gravel or rock.

Suppose you took a graduated cylinder and filled it with sand up to the 50-mL mark. What would happen if you then poured water into the same cylinder? Could you add water without going above the 50-mL mark? If you said yes, you are correct. The water that you add will sink into the sand. This process, in which water sinks down into the ground, is called **infiltration.**

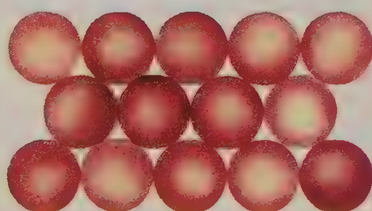


Figure 7-12. Pore spaces among round-shaped particles of loose materials can account for about one third of the total volume.

If you've ever seen sand, you know that it is made up of individual grains. If you look at grains of sand under a magnifying glass (see Figure 7-11), you will notice that the grains are rounded. You will also notice that the grains are more or less the same size. If you fill a container with round-shaped particles, there will be spaces between the particles, as shown in Figure 7-12. You can see this very easily by looking at a glass full of marbles.

Library research

Some people claim they can find underground water with a stick. This is called water witching or dowsing. Prepare a report on this technique of finding water. Do you think it is scientific? Support your reasoning.

The open spaces between particles of sand or soil are called **pore spaces.** The total volume of the pore spaces in a certain volume of material is called its **porosity.** The porosity of sand is about 35%. That means that in 50 mL of sand, there is about 17.5 mL of open pore spaces.

It is easy to recognize that loose soil, sand, and gravel have pore spaces and are therefore porous. But what about rock? Can rock also be porous? The answer is yes, but the degree of porosity varies with the kind of rock. Sandstone, for example, is quite porous. It is made of particles of sand that are cemented together by some mineral. Frequently there are pore spaces between the sand grains and the cementing material. Other kinds of rock, such as granite, which may consist of interlocking crystals or tightly pressed layers, will have a very low porosity or no porosity at all.

Check yourself

1. What two conditions are needed in order for water to be able to infiltrate a material?
2. Into which rock will more water infiltrate, sandstone or granite? Explain your answer.

Water soaks into the ground

What does it mean to say that sand has a high permeability?

Water does not infiltrate into all materials at the same rate. Water will infiltrate into a dry sandy soil almost immediately. But water may form a puddle on top of a clay soil, infiltrating into that kind of soil very slowly. Because water can flow quickly down through sand, we say that sand has a high **permeability.** Permeability is the ease with which water flows through a material. The higher the permeability, the faster a liquid can pass through the material.

Porosity and permeability are closely related, but they are different. A rock with a high porosity does not necessarily have a high permeability. Some sediments, such as clay, can have a high porosity and a low permeability. This is because permeability depends on the number and size of the pore spaces and whether these pore spaces are interconnected.

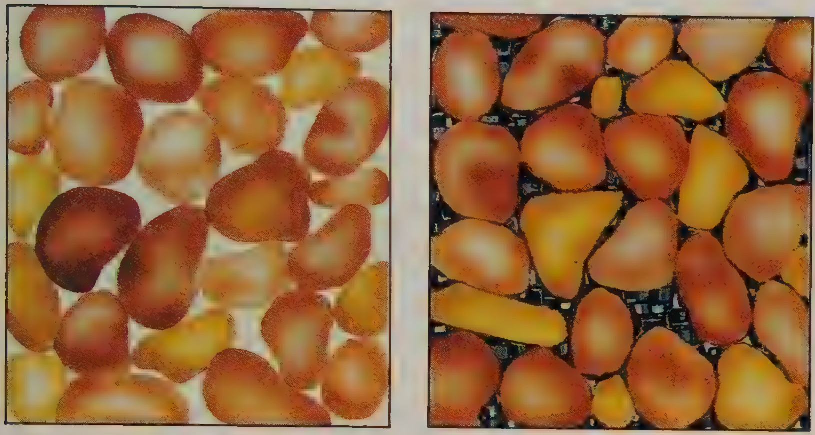


Figure 7-13. Particles of silt and clay may be many times smaller than sand particles. When they fill the pore spaces among sand particles (as shown in the picture on the right), they greatly reduce the permeability of the material.

In nature, soil can contain some round-shaped materials. It also probably contains irregularly shaped materials like clay, which is made up of flat, irregular particles that may be many times smaller than sand particles. Because of the varying amounts of materials of different sizes and shapes in soils, the number and size of pore spaces will vary.

Another factor that affects the size of pore spaces and permeability is packing. Water will pass much more quickly through loosely packed soil than it will through soil that is tightly packed. When soil is tightly packed, the flat particles of clay can fit together almost like a jigsaw puzzle. Water passes through such material very slowly, if at all. The soil becomes more tightly packed as the distance below the surface increases. It becomes more tightly packed at greater depths because the weight of the overlying materials pressing down on it is greater.

Pore spaces are not always needed for high permeability. A rock such as basalt or granite is not very porous. But if it has cracks in it, and the cracks are interconnected, water can pass through very rapidly. Basalt, granite, and other such kinds of rock would have a low porosity but a high permeability.

Check yourself

1. Describe a situation in which a material has a high porosity but a low permeability.
2. Describe a situation in which a material has a low porosity but a high permeability.

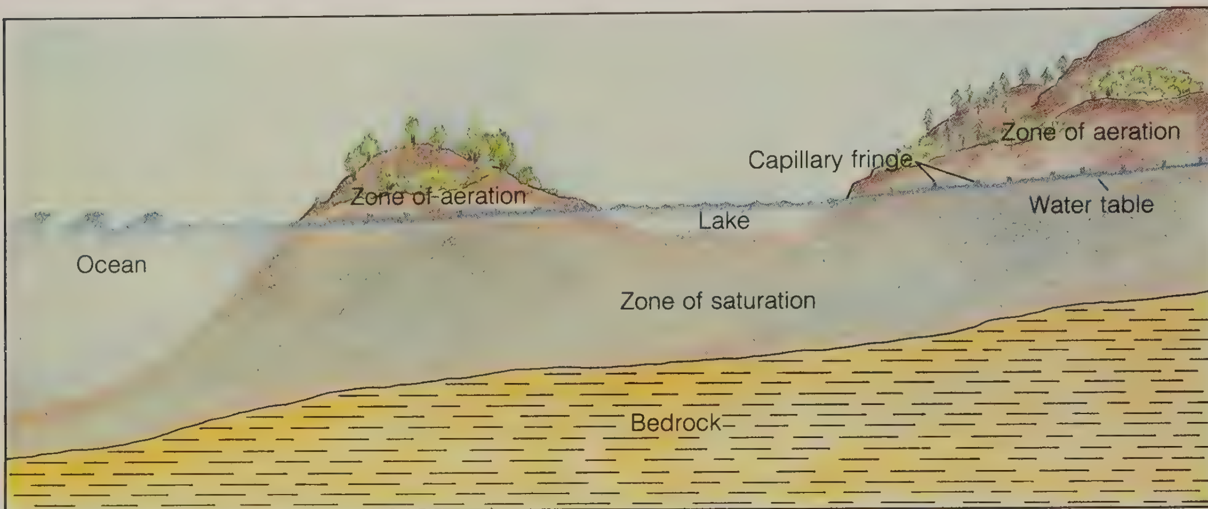


Figure 7-14. In the zone of saturation, the pore spaces are filled with water. What do the pore spaces in the zone of aeration contain?

Zones of water in the ground

The water that infiltrates the earth's surface becomes part of the huge supply of water stored in the ground. It is called **ground water.** Gravity acts on ground water, pulling it downward through the pore spaces, cracks, and other openings in the ground.

The amount of water in soil often varies, depending on the depth of the soil below the surface. After a rain has soaked into the ground, the layer of soil near the surface is usually moist, but not soaking wet. Most of the rainwater has passed down through the pore spaces of this layer and is in a lower layer of soil. But some water does remain behind, clinging to the soil particles at or near the surface. This layer of the soil is known as the **zone of aeration** (see Figure 7-14) because the pore spaces in this layer contain air as well as water.

Water clings to soil particles in the zone of aeration because water molecules are attracted to many other kinds of molecules. This attraction of water molecules to other kinds of molecules is called **adhesion.** It is this process of adhesion that keeps the soil in the zone of aeration damp long after it rains.

As long as the ground is permeable, gravity continues to pull ground water deeper into the earth. But at some point the ground water reaches a layer of soil or rock that is **impermea-**

ble, or not *(im-)* permeable. It allows no water to pass through. This is known as the impermeable layer.

Once the descending ground water hits an impermeable layer (the bedrock in Figure 7-14), it begins to collect there. Ground water will fill up the pore spaces above the impermeable layer. As the pore spaces fill with water, the soil or permeable rock becomes saturated. This saturated layer of soil or permeable rock is known as the **zone of saturation.**

If you pour 10 mL of water into a cylinder containing 50 mL of sand, some of the water will gradually sink to the bottom of the cylinder, which is impermeable. Some of the water will adhere to the sand, making it damp. The descending water will then form a zone of saturation. After all water has descended to the zone of saturation, there will be a boundary where the water-filled zone of saturation meets the layer of particles above it. This boundary, which is the top of the zone of saturation, is called the **water table.**

Library research

Scientists have calculated how much water empties into the sea from the major rivers of the world. See if you can find this information. Make a list of these rivers and their discharge.

Some water in the soil moves upward, against the downward pull of gravity. This upward movement of water in soil is called **capillary action.** You have probably seen examples of capillary action, but never realized what it was. Have you ever seen water soaked up by a sponge, a piece of paper toweling, or a blotter? If you have, then you have observed capillary action. You can observe capillary action at home by taking a small amount of water, placing the end of a paper towel in the water, and watching what happens.

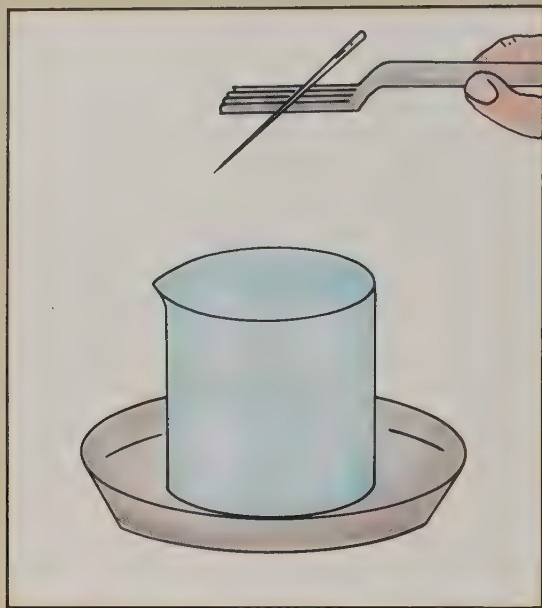
What causes capillary action?

Capillary action is caused by cohesion and adhesion. **Cohesion** is the attraction of one molecule to another molecule of the same kind. Adhesion, as already mentioned, is the attraction of one molecule to a molecule of a different kind. By the process of adhesion, water molecules at the top of the water table are attracted to molecules of the soil particles above. Then, when water molecules have attached themselves to molecules of soil particles, they attract other water molecules to themselves by the process of cohesion.

In soil, these forces of adhesion and cohesion lift a little water upward from the zone of saturation to an area called the **capillary fringe,** which is just above the water table. (See Figure 7-14).

The damp soil in the zone of aeration receives its moisture

Activity Observing the Cohesion of Water Molecules



Materials

pie tin
fork
several needles
soap or detergent (granular)
beaker
water
eyedropper

Purpose

To see if you can make a needle stay on the surface of water.

What to Do

1. Put a beaker in the middle of a pie tin. Fill the beaker with water. When the water is just about even with the top of the beaker, stop.
2. Using the eyedropper, add more water to the beaker. Continue until the water is above the top of the beaker.
3. Place the needle on the fork and hold the fork so that the needle is horizontal. Try to make the needle "float" on the water by gently lowering the fork and needle to the surface of the water.
4. It is important to lay the needle on the water as gently and evenly as possible. Also, it may be necessary to make several attempts before you get a needle to stay on the surface of the water.
5. Once you get a needle to stay on the surface, begin adding a few grains of soap powder.

Questions

1. What might explain why you can add water above the edge of the beaker? Review page 355.
2. What keeps the needle from sinking to the bottom?
3. What happens to the needle when you add soap powder?

Conclusion

What did the soap powder do to the cohesion of the water molecules?

from water that infiltrates down from the surface. The soil particles in the capillary fringe get their moisture from the zone of saturation by capillary action. If the pore spaces in the capillary fringe are small, the water will rise higher than if the pore spaces are large. The height of the capillary fringe ranges from about 2.5 cm or less in sands and gravels to as much as 60 cm or more in silty soils.

Check yourself

1. What is found in the pore spaces in the zone of aeration? in the capillary fringe? in the zone of saturation?
2. Describe what happens as a result of adhesion and cohesion in the capillary fringe.

Water comes out of the ground

In general, the water table is more or less parallel to the earth's surface. But if, as shown in Figure 7-14, the ground slopes or the impermeable layer slopes, then gravity will cause ground water to move toward the lowest level. This movement of ground water usually is very slow because of the small size of the underground pore spaces and interconnections through which it must pass.

Springs. If the water table intersects the earth's surface on a slope, the water will flow onto the surface of the land. The place where ground water flows out of the ground is called a **spring.** Sometimes the water from springs collects in hollows or basins to form marshes, ponds, and lakes. If the springs are located in the hollow, then the place where the springs come out of the ground is under the water. Many ponds and lakes are fed by underwater springs.

What is a spring?

A spring can also feed water into a stream. This happens when the spring is not located in a hollow or basin. Then the water runs downhill off the surface, finding or creating a channel over a period of time.

Careers Hydrologist / Heavy-Equipment Operator

Hydrologists use instruments to measure the flow of water in streams and rivers.

Hydrologist Hydrologists are scientists that map and measure water flow to and from bodies of water such as rivers and lakes. With increases in the use of water by industry and by an expanding population, many companies will be adding water experts to their staffs to advise on water problems such as how to obtain clean water, how to recycle water, and how to handle liquid wastes.

Hydrologists study the occurrence and movement of water on and below the surface of the earth. They work on problems of how to control it and develop it for use by people and industry. For example, some hydrologists work on projects such as water resources, irrigation, flood control, and soil erosion.

Students desiring to enter this career should be in good physical health and enjoy working out of doors. Biological, earth, and physical sciences should be taken in high school. Several higher level mathematics courses are also required.

The minimum requirement for entering this field is a Bachelor of Arts or Bachelor of Science degree in one of the physical or geological sciences. Graduate degrees are required for those wishing to advance in the field or for positions in research, teaching, or administration.

Heavy-equipment operators use backhoes to dig trenches for underground water pipes.

Heavy-Equipment Operator (Water Department) When a home or business needs new or additional water service, or when a pipe between a water main and a building must be repaired, the water department of the city or town does the work.

A water department crew usually consists of a supervisor, two laborers, two plumbers, and a heavy-equipment operator (HEO). HEOs primarily operate backhoes and truck cranes. A backhoe is used to dig trenches and a crane is used to put pipes into place.

HEOs must be skilled, well-coordinated, and alert. One way in which you might learn the skills of an HEO is through a union apprenticeship program in the construction industry. To be eligible for a water department HEO position, you must pass a civil service exam. You should check with your city or town, or with your state civil service office, for information about the exam.

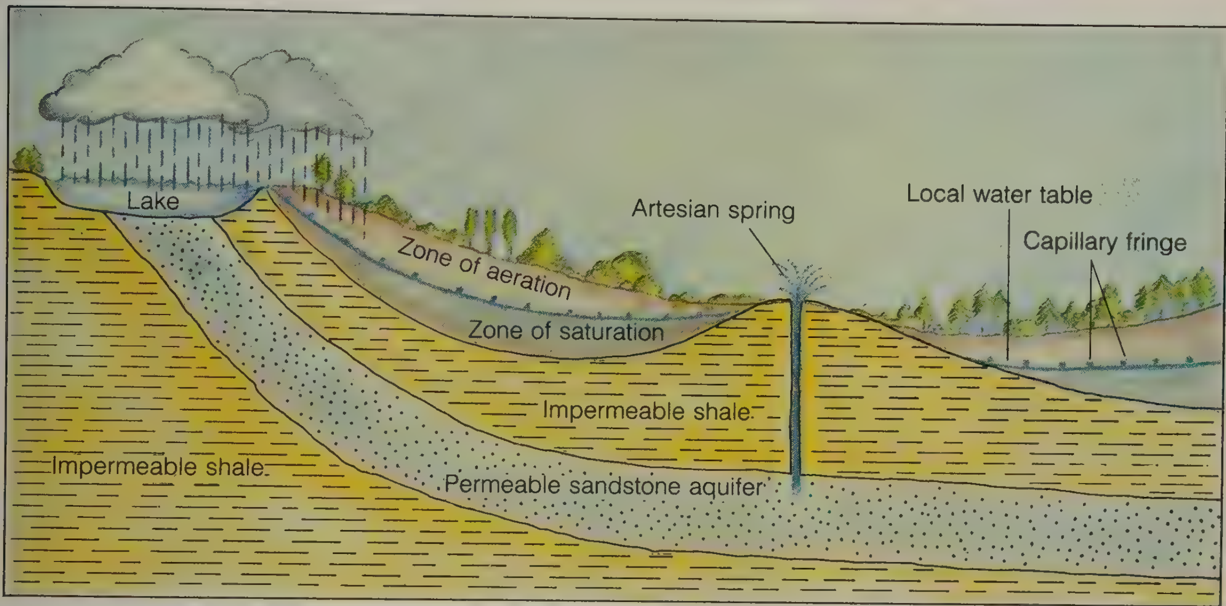


Figure 7-15. Why is the middle layer of rock in an artesian system called an aquifer?

Artesian systems. There is a type of spring that is not fed by water from the local water table. In the states of Kansas, Nebraska, Texas, North Dakota, and South Dakota, there is very little annual rain and snow to supply underground water. Yet this Great Plains region has a good water supply. Where does the water come from?

Beneath this Great Plains region and extending westward to the Rocky Mountains there is a special arrangement of underground rock layers. It is made up of three layers of rock. A middle layer of permeable rock passes between two layers of impermeable rock. This combination of rock layers is called an **artesian system.** A simple artesian system is shown in Figure 7-15. In an artesian system, the middle layer of rock is permeable. Because water passes through this layer, it is called an **aquifer.** The word *aquifer* comes from two Latin words that mean "to carry water." Aquifers are often layers of sandstone or gravel.

Water traveling through an aquifer travels through very small pore spaces in rock. Travel is therefore slow. Depending on the length of the aquifer, it may take hundreds and even thousands of years for water to travel the full length of the aquifer.

Library research

Prepare a report on artesian wells and/or the mining of water from deep in the earth. In what areas of the world is water stored deep in aquifers? (Some water dates back to the Ice Ages.) What is the danger of entering such aquifers in search of water?

The top and bottom layers of an artesian system are impermeable. These two layers of impermeable rock, between which the aquifer passes, prevent water from leaving the aquifer once the water enters it. Shale, a rock formed from particles of clay and silt, is practically impermeable. Shale is commonly found in artesian sytems.

The collecting area of an artesian system can be very far away. In the case of the sandstone aquifer (known as the Dakota sandstone) that brings water to the Great Plains, the collecting area is in the Rocky Mountains. Much of the water that enters the aquifer in the Rocky Mountains is from the snow that melts in the springtime. The water is very cool and pure.

Artesian springs. The water that enters the aquifer in the Rocky Mountains is at much higher levels than the Great Plains. The water flows downward through the aquifer because of the force of gravity. This downward flow and the weight of the water force the water in the aquifer to the surface wherever there is a crack or break in the layer of impermeable rock above the aquifer. The flow of water from an aquifer is called an **artesian spring.** Due to pressure in the aquifer, water from an artesian spring sometimes gushes up above the surface like a fountain.

What is an artesian spring?

Geysers. Sometimes water erupts from the earth in a spectacular way. In areas of volcanic activity, ground water may sink to great depths through very deep cracks. Here it is heated by hot magma or by hot igneous rocks. Because the pressure is much greater at these depths, the boiling point of water is raised well above 100°C. Suddenly, the superheated water changes to steam that forces the water resting on it out through openings in the rock above. Such a feature where water and steam are erupted out of the earth's surface is called a **geyser.**

Geysers can be found in New Zealand, Iceland, and Yellowstone National Park in Wyoming. One of the best known geysers is Old Faithful in Yellowstone National Park, which sends about 40 kL of water as high as 45 m into the air with each eruption. Old Faithful got its name because the time of each eruption used to be fairly predictable, erupting about once

Figure 7-16. A geyser is a spring of hot water and steam that gushes out of the ground. Where does the water in a geyser obtain its heat?

Library research

Find out how the flow of streams is measured. Explain these techniques to the class. How is the speed and volume measured? Why would a scientist want to know this information?

every 65 minutes. Most geysers, however, are very irregular in the time of their eruptions.

Check yourself

1. What causes an artesian spring to gush up out of the ground? Draw a diagram that shows this.
2. Compare an artesian spring and a geyser. How are they similar? How are they different?

Activity Simulating the Water Table

Materials

jar
sand
gravel
water
grease pencil or
masking tape

Purpose

To build a model of a water table.

What to Do

1. Fill the jar with a mixture of sand and gravel, using any proportions of sand and gravel that you choose. Or you may use all sand or all gravel.
2. Slowly pour water onto the mixture (soil) in the jar. Wait a few minutes. While waiting, observe what happens to the water you just poured onto the soil.
3. Add more water until a section of the soil near the bottom of the jar is saturated.
4. Wait until all the water has had a chance to sink in. With a grease pencil or strip of tape, mark the jar at the place that separates the saturated soil from the rest of the soil.
5. On a piece of paper, make a diagram of the jar. Label each of the following: impermeable layer, zone of saturation, water table. Also show where you think the capillary fringe and zone of aeration are.
6. Put your jar away and observe it in a day. Check to see if the water table is at the marker.

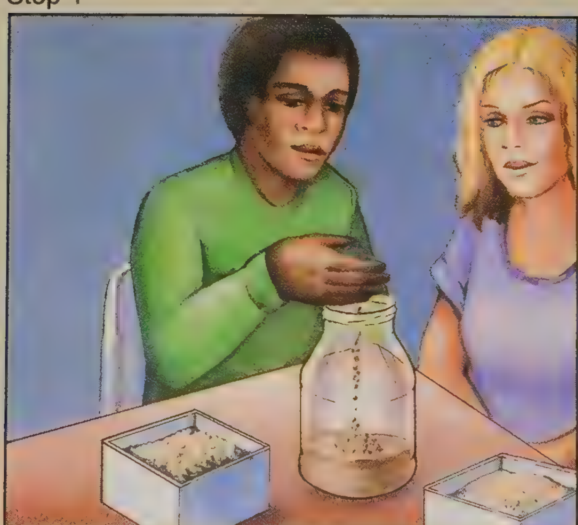
Questions

1. What do you call the process by which the water sinks down into the soil? How long did it take?
2. What do you call the boundary line between the saturated soil and the rest of the soil?
3. Is the water table at the marker on the second day? What do you think caused the change? How can you prevent the lowering of the water table in the jar?

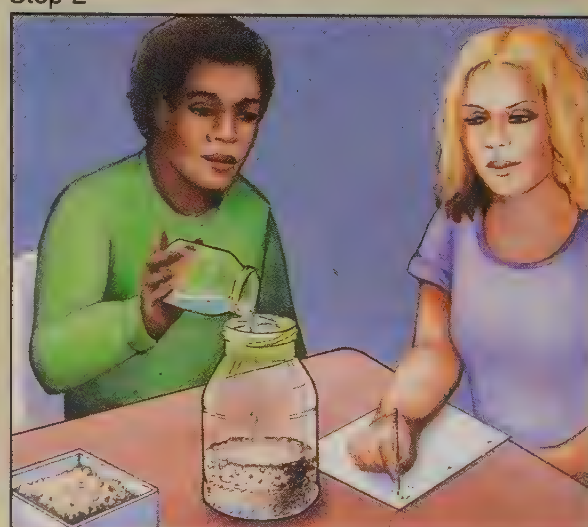
Conclusion

Does the water table in the earth act like that in your jar? Does the level of the water table affect the community?

Step 1



Step 2



Section 2 Review Chapter 7

Check Your Vocabulary

adhesion	impermeable
aquifer	infiltration
artesian spring	permeability
artesian system	pore spaces
capillary action	porosity
capillary fringe	spring
cohesion	water table
geyser	zone of aeration
ground water	zone of saturation

Match each term above with the numbered phrase that best describes it.

1. The process by which water sinks into the ground
2. Spaces between particles of sand or soil
3. The total volume of the pore spaces in a certain volume of material
4. How easily water flows through a material
5. Water that has infiltrated the earth
6. The layer of soil between the water table and the earth's surface
7. The attraction of water molecules to other kinds of molecules
8. Allowing no water to pass through
9. The layer of soil below the water table
10. The boundary between the zone of aeration and the zone of saturation
11. The upward movement of water in soil due to adhesion and cohesion
12. The attraction of one molecule to another molecule of the same kind
13. An area just above the water table that receives its moisture by capillary action
14. The place where ground water flows out of the ground because the water table has intersected the earth's surface
15. A combination of rock layers in which water passes downward through an aquifer
16. A layer of permeable rock through which water travels
17. A natural flow of water from an artesian system
18. The eruption from the ground of water and steam that has been heated by hot magma or rocks in the earth's crust

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Because of _?_, ground water flows toward the lowest level.
   a) gravity c) capillary action
   b) impermeability d) shale and clay
2. An aquifer is often a layer of _?_.
   a) shale c) clay
   b) sandstone d) bedrock
3. Water travels through an aquifer _?_.
   a) quickly c) very slowly
   b) fairly quickly d) as steam

Check Your Understanding

1. What three factors affect permeability?
2. What three factors affect porosity?
3. Why is the water table not permanent in its location?
4. Explain why heavy rains have no effect on an artesian spring.
5. In which earth material would water rise higher by capillary action—particles of small size or of large size? Explain your answer.

Chapter 7 Review

Concept Summary

In the **water cycle,** water is continually recycled between the earth's surface and the atmosphere, changing form (through evaporation, condensation, and freezing) because of different atmospheric conditions.

- ☐ Water on the earth is found in all three states of matter.
- ☐ When water evaporates, it changes from a liquid to a gas (also called vapor).
- ☐ When water condenses, it changes from a gas to a liquid or solid.
- ☐ When water freezes, it changes from a liquid to a solid.
- ☐ On a worldwide basis, the water cycle is a balanced system in which just as much water leaves the earth's surface as returns to it.

Infiltration is the process by which water sinks into the ground.

- ☐ The rate at which water can infiltrate a material depends upon its porosity and permeability.

Porosity is the total volume of the pore spaces in a material.

- ☐ The porosity of a material is affected by the shape of the particles, the size of the particles, and how tightly the particles are packed together.
- ☐ Even rock can be porous, but the degree of porosity of a rock varies with the kind of rock. (Sandstone, for example, is quite porous.)

Permeability is the ease with which water flows through a material.

- ☐ The permeability of a material is affected by the number of pore spaces, the size of the pore spaces, and whether the pore spaces are interconnected.
- ☐ An aquifer is a layer of permeable rock (often sandstone) between layers of impermeable rock.
- ☐ The flow of water through an aquifer, even though quite permeable, can be very slow.

Putting It All Together

1. Describe each of the different states of water. Explain what causes water to change from one state to another.
2. Draw a diagram that shows what happens in the water cycle, using labels as needed.
3. Draw a diagram that traces water from precipitation out of a cloud to water in a river entering the ocean. Label the main parts of a river runoff system.
4. Where on the earth is water, in each of its physical states, found?
5. What are tributaries? How do they function in a watershed system?
6. Draw a diagram that shows the different zones of water in the ground.
7. Describe the capillary action that occurs in soil beneath the earth's surface.
8. Draw a diagram of an artesian system. include an artesian spring.
9. Explain how water can travel through a rock. In your explanation, include the terms *porous, permeable,* and *impermeable.*
10. How and why are geysers related to volcanic activity?

Apply Your Knowledge

1. How is the water cycle important to the earth as an environment for life?
2. How are the water cycle and climate related? Describe variations that you would expect within the water cycle from one climate zone to another.
3. How can freezing temperatures affect the rate at which water infiltrates the ground?
4. In what ways can floods be prevented?
5. Explain how the nature of the earth's surface determines the amount of precipitation that will infiltrate the ground and become ground water.

Find Out on Your Own

1. What major river do you live closest to? Make a list of all the rivers and large streams that are its tributaries. Make a map of the watershed for your river, showing the river, its tributaries, and any divides.
2. Using earth materials such as sand, clay, and gravel, construct a working model of an artesian system and an artesian well. Explain the parts and their functions to the class.
3. Measure the flow of a stream. You can find the velocity of a stream by floating a cork a known distance and timing it. Try this during wet and dry periods. Report your findings to the class.
4. Visit a nearby lake or pond. Find out how it was formed. Is there any evidence that the lake was higher or lower than it was when you observed it? Is the lake filling in with sediments and plants? Where does the lake get its water? Prepare a report that answers such questions.

Reading Further

Arnov, Boris. *Water: Experiments to Understand It.* New York: William Morrow, 1980.

Thirteen experiments show the properties of water. Exceptional drawings by Mr. Maestro.

Bauer, Ernst. *Wonders of the Earth.* New York: Franklin Watts, 1978.

Describes many water features, including geysers, waterfalls, and caves. Illustrated with maps. Recommended for recreational reading as well as for school use.

Emil, Jane. *All About Rivers.* Mahwah, NJ: Troll, 1984.

Explains how and where a river begins. Describes erosion, drainage basins, deltas, the Continental Divide, and flooding and its prevention. Colorful diagrams.

Leopold, Luna, and Kenneth Davis. *Water.* New York: Time Incorporated, 1977. Part of the *Life* Science Library.

Relates the nature of water, what it does, and how it is used by people.

Robinson, Bart. *Columbia Icefield: A Solitude of Ice.* Seattle: The Mountaineers-Books, 1981.

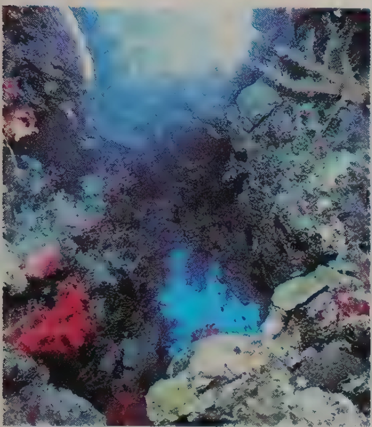
A short, interesting account of the Columbia Icefield of Canada. Describes glaciers and their exploration. Excellent illustrations.

Schultz, Gwen. *Icebergs and Their Voyages.* New York: William Morrow, 1975.

Traces the story of icebergs. Includes their origins and physical characteristics. Relates their potential use as a future source of fresh water. Well-written book on an unusual topic. Fine illustrations and maps.

Chapter 8

The Ocean



Section 1
The Bottom of the Ocean

From above, not much is evident about the earth's oceans except their immense size and the action of the waves that move across their surface.

Until recently, the topography of the ocean bottoms was a mystery. We now know that the earth's highest mountains and deepest canyons lie beneath the ocean. We also know that volcanic processes beneath the oceans are responsible for the shape, and the position, of the land areas.

Section 2
Properties of Ocean Water

A large portion of the earth's surface is covered by water. Many of the organisms that live on the earth are marine organisms. They live in the sea.

The ocean environment varies with location. Surface temperatures are warmer than temperatures deep below the surface. Also, as depth increases, great pressure and continual darkness limit the kinds of organisms found in those regions.

Section 3
The Circulation of Ocean Water

The water in the earth's oceans is constantly moving. On the surface, motion occurs in the form of waves. Waves, which are generally caused by storms at sea, move away from the storm center in all directions and often end up by breaking against a rocky shore or sandy beach.

Larger kinds of water movements also occur in the oceans. Huge circulation patterns, similar to the wind belts in the atmosphere, take place in the earth's oceans.

If you've ever stood on the shore and looked out over the water, you've probably noticed that waves increase in height as they approach the beach. The wave pictured on the facing page is breaking in an area near the beach known as the surf zone. What do you think causes waves to break against the shore?

The Bottom of the Ocean Section 1

Section 1 of Chapter 8 is divided into five parts:

The major oceans

Marginal seas

Sounding the ocean bottom

The topography of the ocean bottom

Resources of the ocean bottom

Figure 8-1. The topography of the ocean bottom is as varied as the topography of the land. This coral cave is located beneath the surface of the Red Sea.

Figure 8-2. About seventy-two percent of the earth's surface is covered by water. What four major oceans are indicated on this map?

What are oceans?

Oceans are huge basins of rock that are filled with salt water. Why are ocean basins deeper than the land areas that are known as continents? Is the bottom of the ocean flat or does it have a varied topography just as the surface of the land does? And how have people been able to reconstruct what the deep parts of the ocean basins look like?

The major oceans

If you look up the word ***ocean*** in your dictionary, you will find that the word has more than one meaning. One meaning refers to the entire body of salt water that covers much of the earth's surface. Another meaning refers to the major geographical divisions of this huge body of salt water. Each of these major geographical divisions is also called an ocean. In this earth science book, the word *ocean* is used in both senses.

As shown in Figure 8-2, much of the earth's surface is covered with water. The relationship between land surface and water surface is about 28% land and 72% water. Of the total earth's surface, nearly 71% is covered by salt water. Thus, most of the earth's surface is covered by oceans and seas, and the earth has been called by many people the water planet.

Because so much of the earth's surface is covered by salt water, the major oceans and most seas are connected. The earth's major oceans are the Pacific Ocean, the Atlantic Ocean, the

The Earth's Major Oceans				
Ocean	Surface Area	Average Depth	Volume	Percentage of the Earth's Total Surface Area (514 million km^2)
Pacific	181.3 million km^2	3940 m	714.4 million km^3	35.3%
Atlantic	94.3 million km^2	3575 m	337.2 million km^3	18.3%
Indian	74.1 million km^2	3840 m	284.6 million km^3	14.4%
Arctic	12.3 million km^2	1117 m	13.7 million km^3	2.4%

Table 8-1. Which has the greater average depth—the Atlantic Ocean or the Indian Ocean?

Indian Ocean, and the Arctic Ocean. As shown in Table 8-1, the Pacific Ocean is the largest major ocean. It has the largest surface area, the greatest average depth, and the greatest volume of water. The Arctic Ocean, on the other hand, is the smallest of the major oceans. It has the smallest surface area, the least average depth, and the least volume of water.

If you look at Figure 8-2, you will notice that Antarctica is surrounded by the southern parts of the Pacific Ocean, Atlantic Ocean, and Indian Ocean. The mass of water that surrounds Antarctica is sometimes referred to as the Antarctic Ocean.

The total surface area of the earth's four major oceans is 362 million square kilometers. The total surface area of all the earth's land masses (including glaciers, lakes, and rivers) is 152 million square kilometers.

Library research

Examine maps in various books. Which maps indicate an Antarctic Ocean?

Check yourself

1. What is the ratio of water to land on the earth's surface?
2. List the major oceans in order of size, from the largest to the smallest.
3. List the major oceans in order of depth, from the deepest to the shallowest.

Marginal seas

The margins of the major oceans frequently have smaller seas. **Marginal seas** formed in one of three different ways.

Some marginal seas formed when continents came together. It may seem hard to believe that land masses as huge as continents actually move. But there is evidence that during different eras of geologic history the earth's land masses were positioned

Figure 8-3. Marginal seas formed in one of three different ways. How did the Red Sea form?

differently on the earth's surface. The Mediterranean Sea, which is between the continents of Africa and Europe, is thought to have formed when the two continents enclosed it. The Black Sea, located between Europe and Asia, is another example of a marginal sea that may have formed as the result of continents coming together.

Some marginal seas are separated from the major oceans by chains of islands. The China Sea is separated from the Pacific Ocean by other seas, and they are all separated by series of island chains. Because the island chains are usually curved, they are called **island arcs.** The Caribbean Sea is another example of a marginal sea formed by an island arc.

Some marginal seas are thought to have formed as the result of a structural break in a land mass. The Red Sea and the Gulf of California are examples. In the case of the Red Sea, the continental crust was not only split, but it separated. Ocean crustal rocks have been found in the area of separation.

Library research

Examine maps in various books and find the names of some island groups that separate the China Sea from the Pacific Ocean.

Check yourself

1. What is a marginal sea?
2. Describe the three different ways marginal seas form.
3. List two examples for each type of marginal sea.

Sounding the ocean bottom

In 1492, when Columbus sailed across the Atlantic Ocean, a common notion was that the ocean bottom was flat and featureless. The only method known to determine the depth of the ocean water was to lower a heavy weight tied to the end of a rope into the water until it hit bottom. Then the length of line was measured. Sailors were usually interested in the position of the ocean bottom only if the water became so shallow that their ship might hit the bottom. Consequently they did not carry enough rope to reach the deep ocean bottom.

Four hundred years after Columbus, people were still using the same method for measuring the depth of the ocean. By that time, however, wire had been substituted for rope, and a power-driven winch was used to lower and raise the weight on the end of the wire. Many scientists continued to believe that the ocean bottom was mostly flat. They based their belief on the fact that the bottoms of reservoirs usually become flat because of the sediment that settles out of the water.

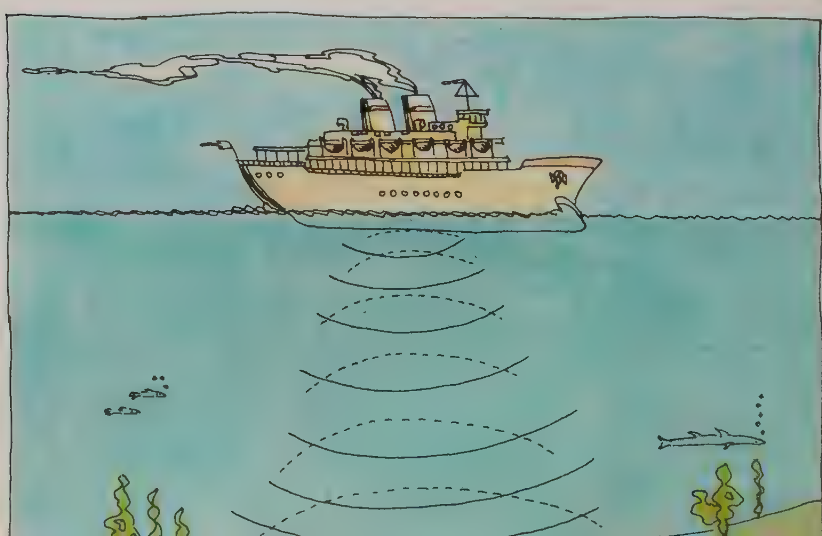
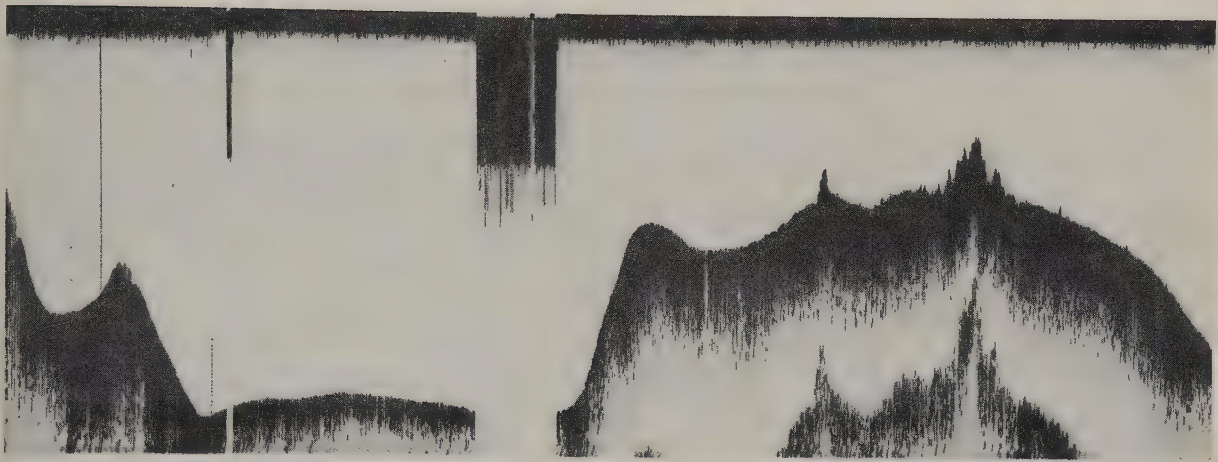


Figure 8-4. How can sound waves be used to measure the depth of the ocean?



In 1925, a more modern method of measuring the depth of the ocean was first used in a detailed survey of the ocean bottom. This method, which uses sound, is called echo sounding. In **echo sounding,** a sharp noise called a ping travels from the ship to the ocean bottom and bounces back from the bottom as an echo. The length of time it takes the ping to make the trip down and back is measured. By knowing how fast sound travels in water, the distance from the ship to the bottom can be calculated.

Figure 8-5. Continuous records of ping echoes recorded on moving strips of paper provide profiles of the topography of the ocean bottom.

In echo sounding, a precision depth recorder makes a continuous record of ping echoes on a moving strip of paper. The pings are sent out continuously as the ship moves, and the paper record is a scale representation of the ocean bottom. An example is shown in Figure 8-5. Thousands of these types of records have shown that the ocean bottom has an even more varied topography than does the land.

Check yourself

1. How was the depth of the ocean bottom measured before the twentieth century?
2. What type of information is produced by the precision depth recorder?
3. What did people learn about the ocean bottom from data provided by the precision depth recorder?

The topography of the ocean bottom

Ocean basins are quite different from the land masses that make the continents. The most obvious difference is depth. Ocean basins are at a much lower level than the land. They sit at a lower level in the earth because they are formed mainly of ocean basin rocks, which are more dense than continental rocks. Ocean basin rocks are mostly basalt, whereas continental rocks are mostly granite and granite gneiss.

Is there much variation in the depth of ocean basins?

The depth of ocean basins can vary greatly from one location to another. But there are several general characteristics that will help you to get a clearer picture of the topography of the ocean bottom. Figure 8-6 shows several general regions of the ocean bottom. It also shows features that characterize each region. These regions and features are associated with certain earth processes.

Near the continents is an area known as the **continental margin.** Most sediment eroded from the land is deposited in this part of the ocean. The continental margin generally consists of a continental shelf, a continental slope, and a continental rise. Submarine valleys and canyons are erosional features of this region of the ocean bottom.

Farther from shore, and at a greater depth, is the deep sea floor. This area is affected by the earth processes of sedimen-

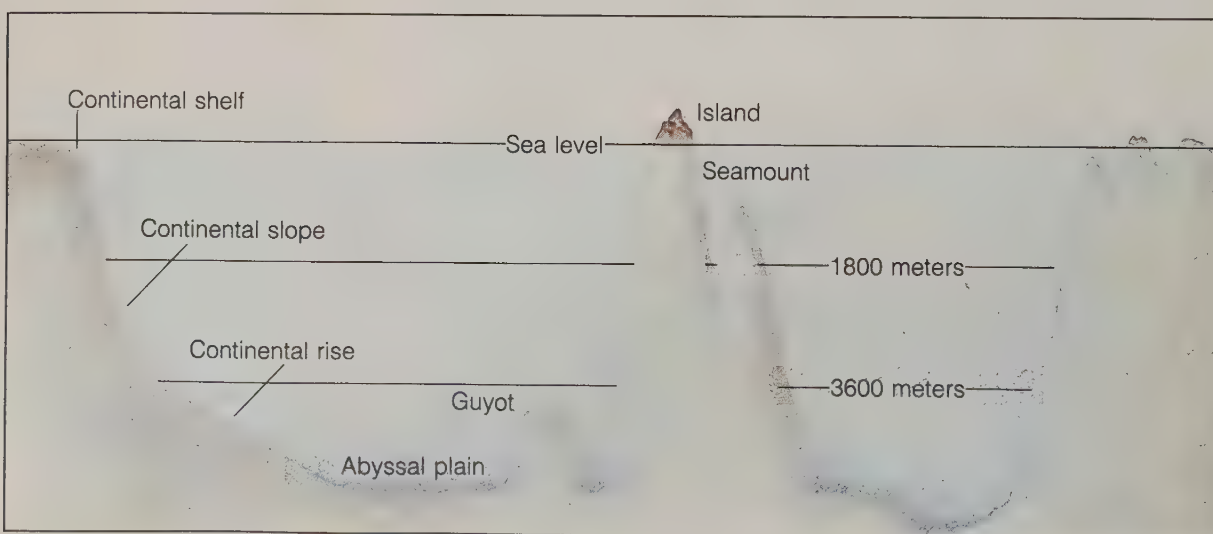


Figure 8-6. Is the water deeper above a continental shelf or above an abyssal plain?

tation and volcanism. Seamounts, guyots (gee-ŌZ′), abyssal plains, trenches, and mid-ocean ridges are features that make up the deep sea floor.

In what part of an ocean basin is the mid-ocean ridge located?

Our Science Heritage

The *Nautilus* and the *Challenger*

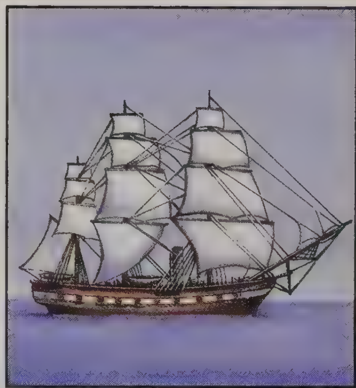
Before the twentieth century, with its invention of airplanes and its space age technology, people crossed the ocean only by ship. Some of the voyages down through history have become famous. Among those that come to mind are the voyages of Christopher Columbus, Ferdinand Magellan, James Cook (known as Captain Cook), and Charles Darwin. You can certainly think of other famous voyages.

Some totally fictional voyages have also become quite famous. Thanks to the genius of its author, Jules Verne, many people are very familiar with the detailed account of the *Nautilus* in *Twenty Thousand Leagues Under the Sea*, published in 1870. But how many have ever heard of the *Challenger* expedition (1872–1876)?

From the resources of his remarkably creative (and in some ways prophetic) imagination, Jules Verne was able to describe an undersea world that had never been visited and a submarine that had never existed. In the world of science, however, it took considerably more time to develop a picture of the world under the sea.

In the world of science, the voyage of the *Challenger* represents the first organized expedition whose purpose was to gather data about the earth's ocean basins and their contents.

The *Challenger* was a surface vessel, far less exciting than the *Nautilus*. And the *Challenger* had to gather all its data by means of simple instruments like jars and nets that were lowered on wires from the surface. But after three and a half years at three hundred and fifty observation stations throughout the earth's oceans, enough data had been collected to fill fifty volumes. And the science of oceanography had been born.



The *Challenger* collected enough data on the earth's oceans to form the basis of a new science.

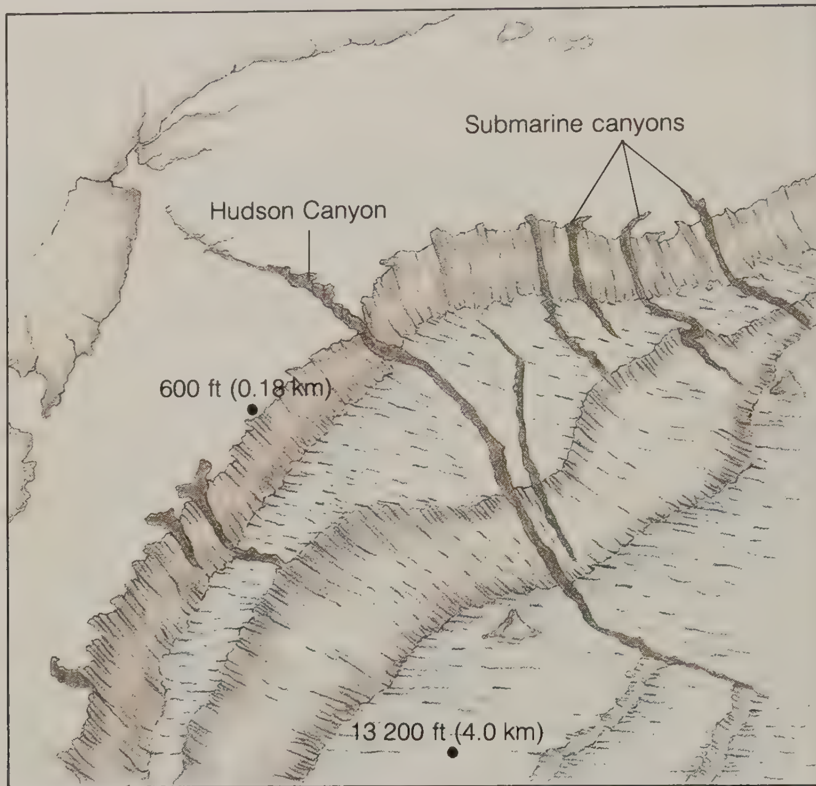


Figure 8-7. How might an underwater canyon have been formed?

How does the continental slope differ from the continental rise?

Features of continental margins. A continental margin is a region that separates a continent from the deep sea floor. The continental margin is not as deep as the abyssal plain because the continental margin is made up of continental crustal materials, rocks, and/or sediments.

Continental margins consist of several parts. The part nearest the land has, on the average, a very gentle slope and is called the continental shelf. At a depth of about 200 m, the steepness increases. This steeper part is called the continental slope. At the base of the continental slope is another, much gentler slope that leads down to the abyssal plain. This gently sloping area is known as the continental rise.

Erosional valleys and canyons cut across the continental margins. Some of these canyons are deeper and wider than the Grand Canyon in Arizona. These valleys and canyons were probably formed by rapidly flowing turbidity currents. *Turbidity currents* are rapidly flowing mixtures of sediment and water. (Flowing particles of sand and other sediments can change a rock surface in the same way that sandpaper can wear away a wood surface.) The canyons and valleys might also have been formed by glaciers during the last Ice Age.

Features of the deep sea floor. Continental margins, which border the continents, are formed of continental crustal rock, sediment, and other materials. Beyond the continental margins, the deeper parts of the ocean basins are formed of ocean crustal rock. All ocean crustal rocks are volcanic, formed by underwater eruptions of dark-colored basaltic flows.

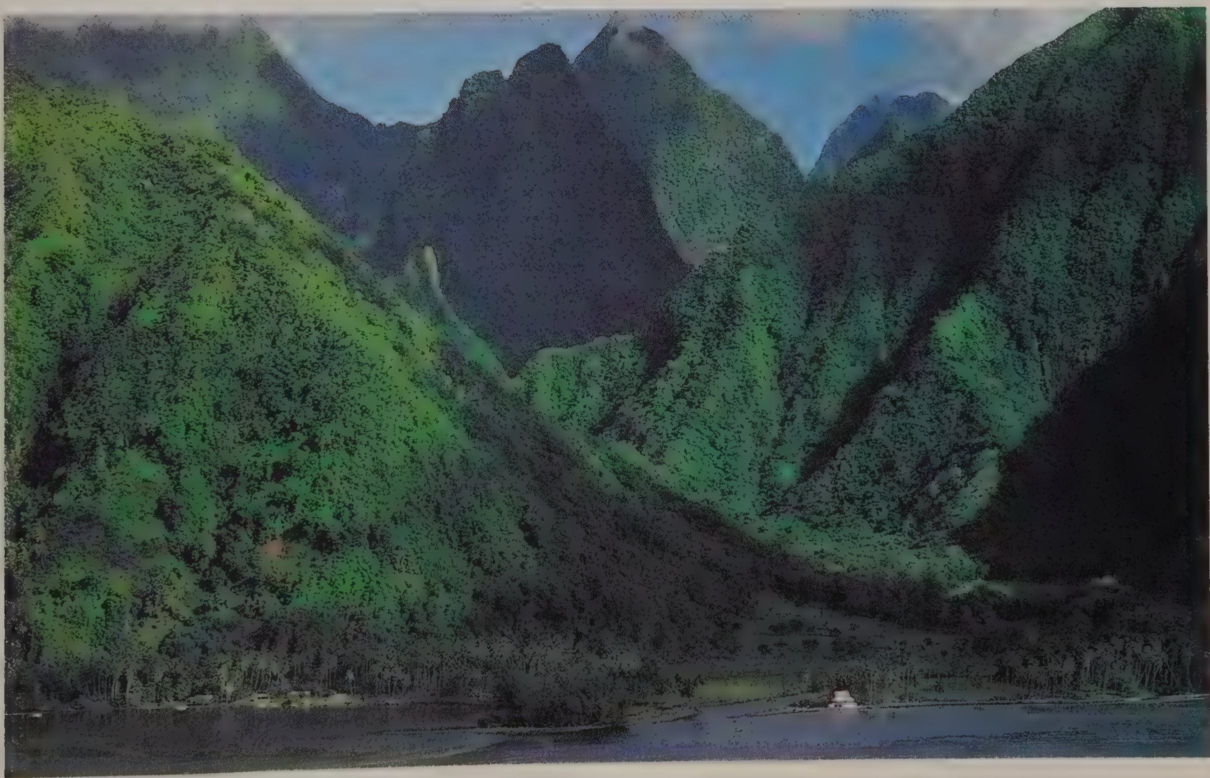
Volcanic action at the ocean bottom causes changes in the crustal features. Among the tallest objects that rise from the deep sea floor are underwater mountains called seamounts. Seamounts are volcanic cones that grow upward from the ocean bottom, layer by layer. Seamounts usually rise more than 1000 m above the ocean floor.

Seamounts sometimes reach the ocean surface and form islands. Virtually all islands in the ocean were formed by volcanic activity. Igneous activity also takes place in the ocean crust beneath these volcanic features. This igneous activity causes additional bulges in the ocean crust.

Library research

Find out more about guyots. What is the origin of their name?

Figure 8-8. Tahiti is an island in the South Pacific. How were virtually all islands in the ocean formed?



Activity Comparing the Density and Elevation of Floating Objects

Materials

1 block of balsa wood and 1 block of a hardwood, each of the same thickness

balance

clear jar or 500-mL beaker

graduated cylinder

water

tub or other container large enough to float the blocks of wood

Purpose

To calculate the density of two different materials and then compare their elevations above water as they float.

What to Do

1. Using the balance, weigh the two blocks of wood and record their mass.
2. If the blocks have a rectangular shape, measure their length, width, and height. Calculate their volume by multiplying length times width times height.
3. If the blocks have an irregular shape, calculate their volume by using the water displacement method described in Chapter 1 on page 29.
4. Calculate the density of each block by dividing its mass by its volume.
5. Pour water into the tub and float the two blocks of wood side by side in the water. Measure and record the difference in elevation of the tops of the blocks above the level of the water.

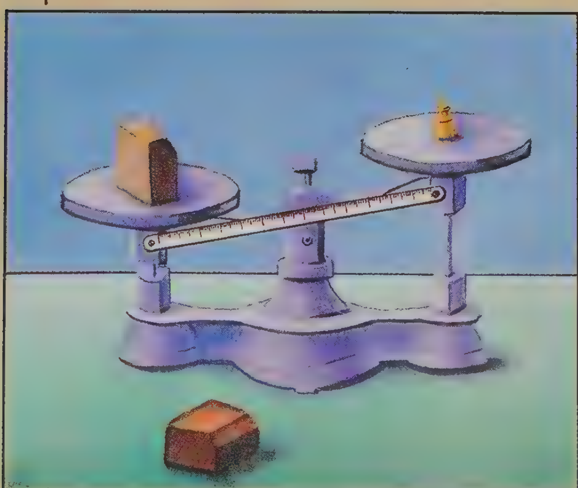
Questions

1. Which block of wood has the greater density?
2. Which block floated lower in the water?

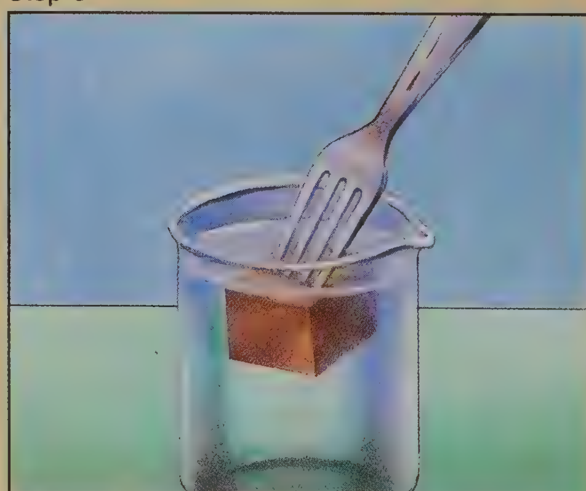
Conclusion

What can you say about the relationship between the elevations and densities of the two blocks?

Step 1



Step 3



Because of wave action or ocean crustal movement, volcanic islands can disappear beneath the surface of the sea. Volcanic islands are attacked by wave action. If the volcanoes have become extinct, then wave action is often able to erode the tops of the seamounts down to sea level. Sometimes the ocean crust beneath extinct volcanoes sinks, lowering the eroded seamounts well below the ocean's surface, forming flat-topped underwater mountains called guyots (gee-OZ′). Guyots, which are found in deeper parts of the ocean basins, can rise to nearly 1000 m above the ocean floor.

Library research

What unusual kinds of organisms are found in the enriched waters around active volcanic rift valleys?

Sporadic turbidity currents spill off the continental margins into the deep ocean. Through time, abyssal hills near continental margins can be covered with hundreds of layers of sediment. Turbidity currents can also extend for hundreds of kilometers across the ocean bottom, leaving large flat areas called **abyssal plains.** Most abyssal plains make up the deeper parts of the major ocean basins at about 5 km depth. These abyssal plains are an example of the flat surface that many scientists once thought the entire ocean bottom was like.

A very small percent of the ocean basin has long deep **trenches** that extend from the deep ocean basin downward to about 11.5 km. Trenches are usually bordered by enough volcanic activity to create island arcs. In the case of the Peru-Chile Trench, the volcanic activity near the trench forms part of the Andes Mountains. The region of volcanic activity that surrounds the basin of the Pacific Ocean is called the **Ring of Fire** and is generally associated with deep sea trenches. (Trenches and island arcs indicate areas of collision between separate oceanic crustal plates.)

The mid-ocean ridges. The rest of the ocean basins is made up of the world's biggest and longest mountain system, the **mid-ocean ridges.** The mid-ocean ridge system is about 65 000 km long. In the Atlantic Ocean, the mid-ocean ridge occupies the central third of the entire basin from the Arctic Ocean to about the latitude of the southern tip of South America. Iceland is a part of the mid-ocean ridge that became an island through volcanic growth.

As shown in Figure 8-9, the mid-ocean ridge passes between Africa and Antarctica and into the Indian Ocean, where it

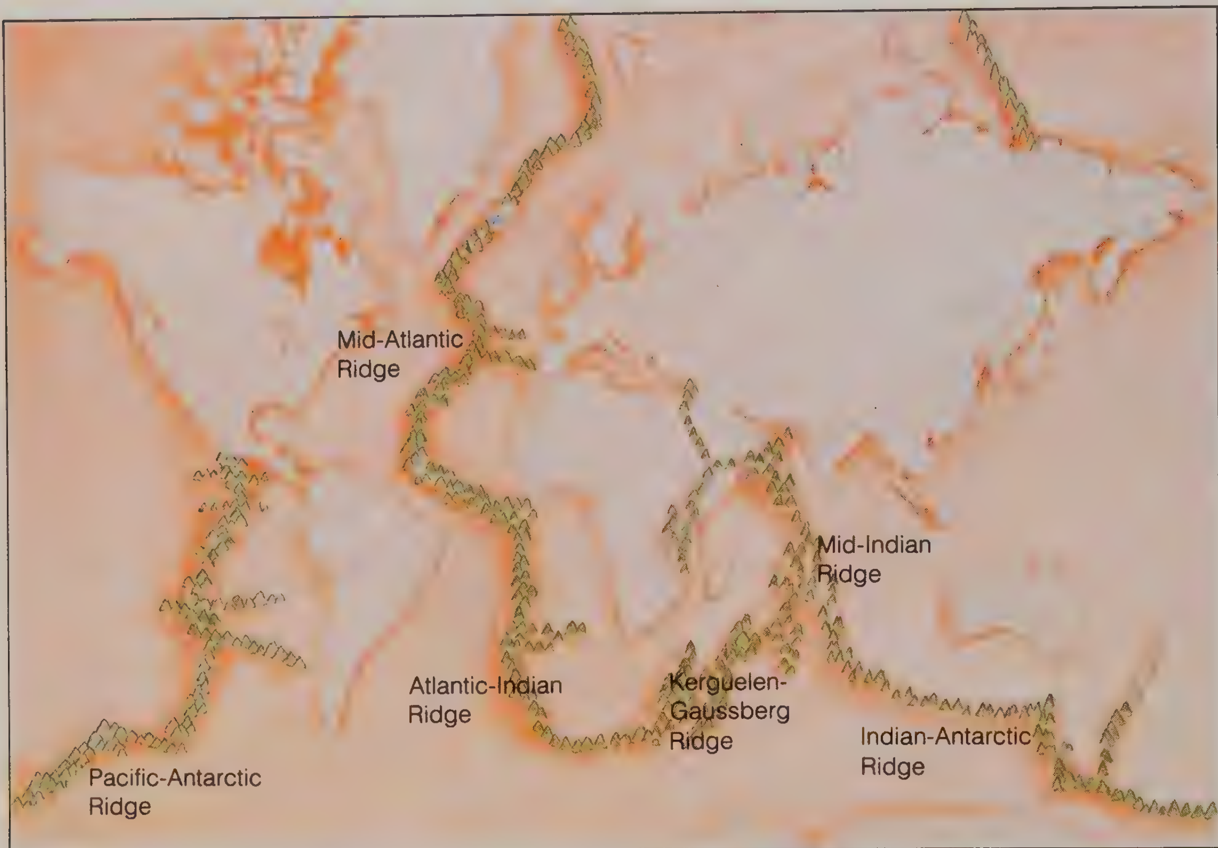


Figure 8-9 Why, in the Pacific Ocean, is the mid-ocean ridge called a rise rather than a ridge?

splits. One branch heads north and forms the Red Sea between Africa and Saudi Arabia. The other branch extends generally southeast and east between Australia and Antarctica and then across the southern portion of the Pacific Ocean.

In the Pacific Ocean, the mid-ocean ridge is less rugged. As a result, it is called a rise. The rise continues under the southeastern part of the Pacific Ocean toward Central America. The rise then branches. Part of it disappears near Panama. The other part disappears near Baja California.

The mid-ocean ridge system is offset by hundreds of breaks in the earth's crust. These breaks are fracture zones that can extend for hundreds of kilometers. The ridge part of the system is extremely rugged. It has a fairly deep central **rift valley** with high peaks near the rift valley, which is a site of active volcanism. Much heat from the volcanic action in this rift valley

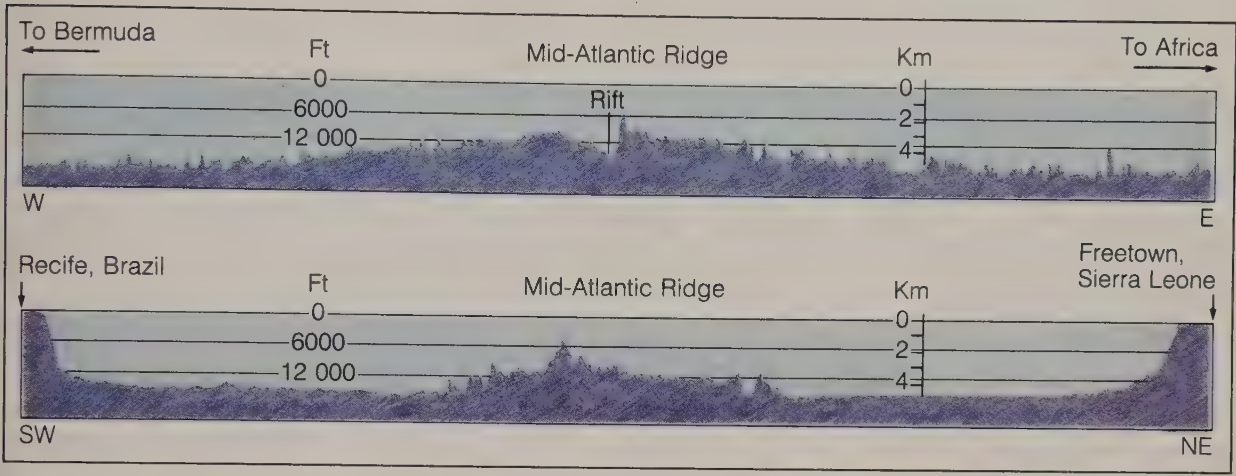


Figure 8-10. These two views show an east-west profile and a northeast-southwest profile of the Mid-Atlantic Ridge system. In which part of the mid-ocean ridge system does volcanic activity take place?

is absorbed by ocean water. In addition, new ocean-floor crust forms at the mid-ocean ridges during volcanism.

Check yourself

1. List the ocean bottom features associated with continental margins.
2. List the ocean bottom features associated with the deep basins.
3. What type of geologic activities affect the permanence of ocean islands?

Resources of the ocean bottom

The ocean bottom contains many resources and is used in different ways.

□ Natural gas and crude oil form and accumulate in the sediments of the continental margins.

□ Gold, diamonds, titanium ores, and other heavy substances are often deposited on continental margins.

□ Sand and gravel deposits in the nearshore environment are used for construction materials.

Activity Taking and Using Soundings

Materials

specially prepared tub of opaque solution

string

small metal weight that does not contain lead

rule

several paper towels or napkins

paper

pencil

Purpose

To take soundings of an underwater surface you cannot see and to use the results to reconstruct topographic features of the underwater surface.

	A	B	C	D	E
1					
2					
3					
4					
5					

What to Do

1. Obtain the specially prepared tub of opaque solution. You should not be able to see the underwater surface of the container.
2. Imagine a grid system over the tub, similar to the one shown on this page. On a blank sheet of paper, make lines that correspond to your grid system. Label all of the spaces in one direction with numbers. Label all of the spaces in the other direction with letters.
3. Tie the weight onto one end of the string.
4. Take a sounding for the area of the tub that is represented by space 1A on your grid. Lower the weighted end of the string into the tub at the proper location. Lower the string until the weight just touches the bottom at that location. The string must be kept tight and straight if you are to get an accurate reading.
5. Raise the weighted string and measure the length of string that got wet. This represents the depth of the solution at that location. Record the depth in the appropriate space on your grid.
6. Wipe the string with a paper towel and take another sounding. Take a total of 16 to 20 soundings. In the appropriate space on your grid, record the depth of each sounding.

Questions

1. On the basis of the data in your grid, what is the shape of the bottom of the container? Draw a map of it, showing the high points and the low points.
2. Pour the liquid from your container into another container. How does your answer to Question 1 compare with the actual shape of the bottom of the container?

Conclusion

Using the same method with the string and weight, how could you determine the shape more precisely?

□ Manganese nodules are found in abundance in many places on the deep ocean floor. They contain copper, cobalt, zinc, and other metals that are valuable.

Why are manganese nodules valuable?

□ Many valuable minerals form around the hot springs associated with the central valleys of the mid-ocean ridge system.

□ The shellfish industry is a resource of the continental shelves.

□ Beaches are commonly used for recreational purposes.

□ The deep ocean floor has been used as a place to dump canisters of waste chemicals. Nerve gas and nuclear wastes are two examples.

Check yourself

1. What types of resources are found in and on the continental margins?
2. What types of resources are associated with the deep ocean floor?

Figure 8-11. Oil rigs are used to obtain oil and natural gas from beneath the sea. Where do natural gas and crude oil form and accumulate offshore?

Section 1 Review   Chapter 8

Check Your Vocabulary

abyssal plain	ocean
continental margin	ocean basin
echo sounding	rift valley
island arc	Ring of Fire
marginal sea	trench
mid-ocean ridge	

Match each term above with the numbered phrase that best describes it.

1. The entire body of salt water that covers much of the earth's surface; also, any of its major geographical divisions
2. A smaller body of salt water found along the margin of a major ocean
3. A chain of islands, usually curved, that separates a marginal sea from a major ocean
4. A method of using noise (pings) to measure the depth of the ocean
5. The region of the ocean bottom near the land areas; contains most of the sediment eroded from the land; separates a continent from the deep sea floor
6. The low-lying earth formation that contains the ocean's water; consists mainly of dense basaltic crustal rock
7. Large flat area of the deep sea floor; formed by sediment flows that spill off the continental margins
8. A long narrow depression of the deep sea floor; generally has steep sides; usually bordered by areas of volcanic activity
9. The region of volcanic activity that surrounds the basin of the Pacific Ocean
10. A system of rugged mountains that extends down the middle of the ocean basins
11. Deep valley in the center of the mid-ocean ridge; a site of active volcanism

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. _?_ are a feature found on the continental margins.
   a) Guyots
   b) Seamounts
   c) Submarine canyons
   d) Trenches
2. An abyssal plain forms from _?_.
   a) sediments being deposited
   b) lava flows from underwater volcanoes
   c) erosion of the mid-ocean ridge
   d) erosion of guyots
3. The ocean with the least amount of water is the _?_.
   a) Arctic Ocean
   b) Atlantic Ocean
   c) Indian Ocean
   d) Pacific Ocean
4. The _?_ is an example of a marginal sea that formed because of an island arc.
   a) Black Sea
   b) Gulf of California
   c) Mediterranean Sea
   d) Caribbean Sea
5. A resource associated with the deep ocean floor is _?_.
   a) manganese nodules
   b) diamonds
   c) shellfish industry
   d) sand and gravel

Check Your Understanding

1. What causes ocean basins to be at a different level than the continents?
2. Describe the technique of echo sounding.
3. Describe the mid-ocean ridge system.
4. What is the reason the earth is sometimes called the water planet?
5. What is the relationship between trenches and volcanic activity?

Properties of Ocean Water Section 2

Section 2 of Chapter 8 is divided into six parts:

Salinity

Temperature and density

Sea ice

Water pressure

Water absorbs light

Resources of ocean water

Figure 8-12. Physical properties like salinity, temperature, and density affect the ocean as an environment for plants and animals. What is another word for *salinity*?

In Section 1 of this chapter, you considered dimensions and features of the ocean bottom. In this section, you will consider some properties of the ocean's water. You will also consider how those properties affect the ocean as an environment for plants and animals.

Salinity

One characteristic that is common to all ocean water is saltiness. All ocean water is salty. But some samples of ocean water are saltier than other samples. Sometimes the difference is so great that you can taste the difference. Sometimes, however, the difference is not that great. For scientific purposes, there is a precise way to determine the saltiness, or salinity, of water.

The words *saline* (which means salty) and *salinity* (which means saltiness or degree of saltiness) are from the Latin word *sal,* which means salt. When speaking scientifically of the salinity of ocean water, the word *salinity* has a more precise meaning. **Salinity** is a measure of the amount of total dissolved materials in water. The salinity of ocean water is defined as grams of dissolved materials per kilogram of ocean water.

What do we know about the materials that are dissolved in ocean water? As shown in Table 8-2, six elements account for over 99% of the dissolved materials in water. Two of those

Table 8-2. What two elements make up over eighty-five percent of the dissolved materials in ocean water?

Elements in Dissolved Materials in Ocean Water

Element	Form Found in Water	Percentage of Dissolved Materials
chlorine	chloride ion	55.0%
sodium	sodium ion	30.6%
sulfur	sulfate ion	7.7%
magnesium	magnesium ion	3.7%
calcium	calcium ion	1.2%
potassium	potassium ion	1.1%
	Total	99.3%

seven elements, chlorine and sodium, which make up common table salt (sodium chloride), are by far the most abundant.

Average ocean water has a salinity of 35 parts per thousand, which means that it has 35 grams of dissolved materials per kilogram of water. Certain environmental changes, however, can affect the salinity of ocean water.

In the upper parts of the major oceans (less than 1 km below the surface), evaporation, rain, river inflow, and vertical mixing cause significant variations. Similar environmental changes also affect the salinity of marginal seas.

The Mediterranean Sea has few large rivers entering it. The Mediterranean Sea also has excessive evaporation, little rainfall, and limited connection to the Atlantic Ocean. Most of the Mediterranean, therefore, has a greater than average salinity of 38 to 39 parts per thousand.

The salinity of the Black Sea, on the other hand, is far less than average. The Black Sea has three major rivers flowing into it. The Black Sea has less evaporation than the Mediterranean and it has only a narrow, shallow connection with the Mediterranean. As a result, the surface salinity of the Black Sea is only 16 parts per thousand.

Library research

Find out what an ion is and why that would be the form of an element found in solution.

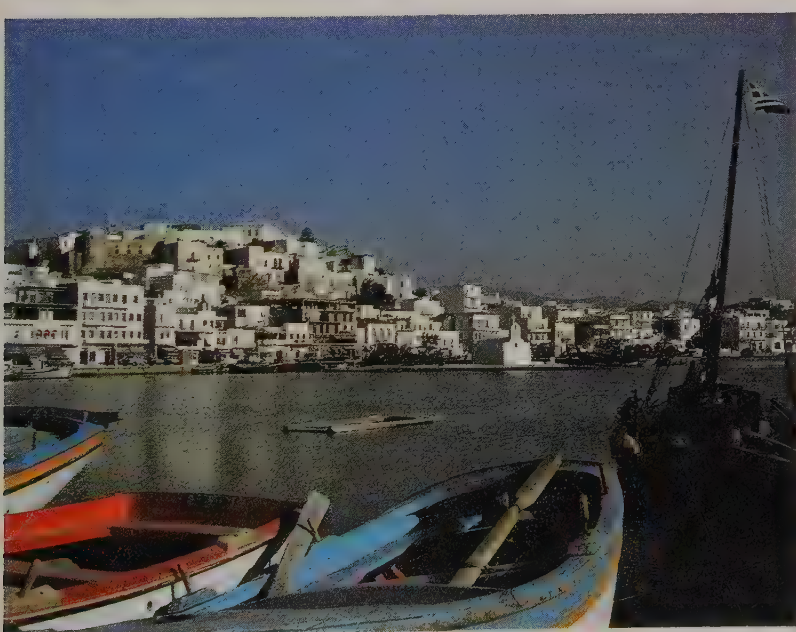


Figure 8-13. The Greek island of Naxos is located in the Aegean Sea, an arm of the Mediterranean Sea. How does the salinity of the Mediterranean Sea compare with the salinity of other bodies of salt water?

Activity Evaporating Salt Water

Materials

jar with about 1 L of tap water

salt

balance and standard masses

large, lightweight container (a clean plastic milk or bleach container with the top cut off will be fine)

filter paper and funnel

Purpose

To see what happens when salt water evaporates.

What to Do

1. Put the filter paper in the funnel. Using the balance, measure 35 g of salt. Put the salt inside the filter.
2. Put the empty container on the balance. Using standard masses, find and record the mass of the empty container.
3. Add a 1-kg standard mass to the pan with the other masses.
4. Holding the filter cone with the salt in it above the empty container, pour tap water through the filter and into the container until the container and the masses balance.
5. Put the uncovered container in a place where the water can remain for a week or more until it evaporates.
6. After all the water has evaporated, put the container on the balance and find its mass.

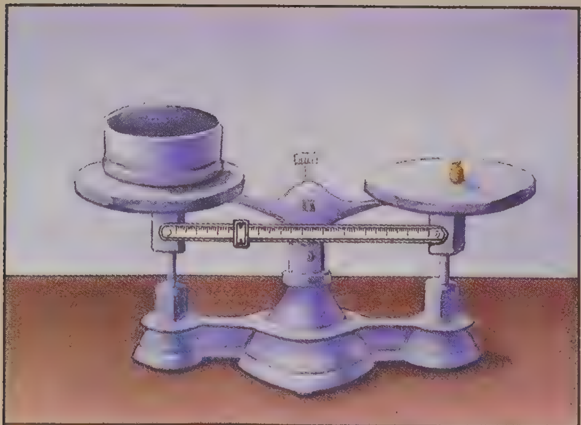
Questions

1. How does the mass of the container after the water has evaporated compare with the mass of the container when you first measured it?
2. How do you explain the difference in mass?
3. Salinity (in parts per thousand) equals grams of salt per kilogram of solution. What was the salinity of your solution when it first began to evaporate? How does that salinity compare with the average salinity of ocean water?
4. How could this activity have been speeded up?

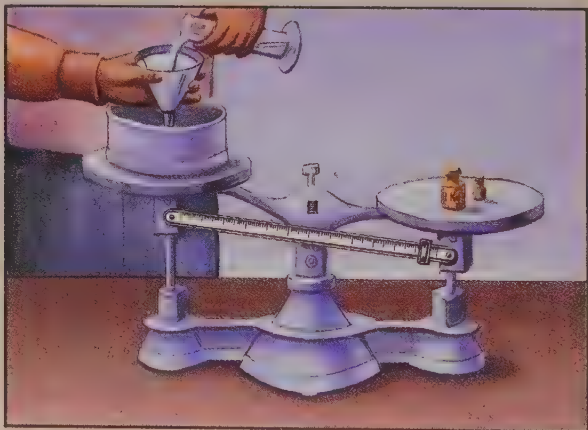
Conclusion

How does evaporation affect ocean salinity?

Step 2



Step 4



In the major oceans, three fourths of the water is below one kilometer depth. At that depth, the salinity is nearly constant at 34.5 to 34.9 parts per thousand. Along the center of the mid-ocean ridges, however, isolated spots have hot springs. These hot waters often contain concentrated amounts of dissolved solids. When deep water circulation is restricted, these hot waters can form brine pools. The bottom of the Red Sea has brine pools with salinities as high as 257 parts per thousand.

What is the salinity of three fourths of all water in the major oceans?

Check yourself

1. How is the salinity of ocean water determined?
2. What types of environmental changes can affect salinity?
3. What six elements make up over 99% of the salinity of ocean water?

Temperature and density

Along with salinity, temperature is one of the most frequently measured properties of ocean water. The surface of the open ocean ranges from very cold in the polar regions to room temperature in tropical areas. This difference in temperature is caused by the variation in solar radiation at different latitudes. As shown in Figure 8-14, at the higher latitudes the sun's rays strike the earth's surface at a smaller (more oblique) angle than they do near the equator. As the angle of incoming radiation decreases, a given amount of solar radiation is spread over larger areas of the earth's surface. As a result, the amount of

Library research

What is a thermocline? Where is it located?

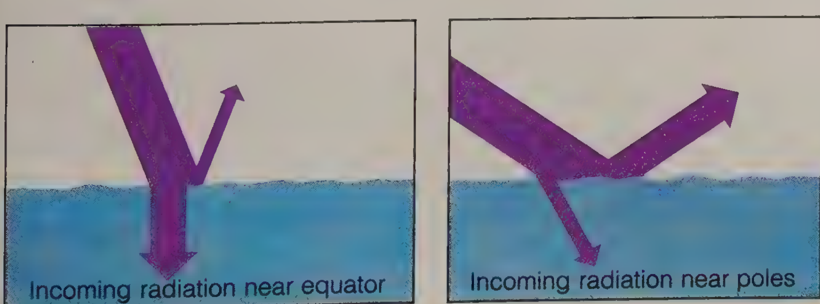


Figure 8-14. How does the angle of incoming solar radiation affect surface temperatures of ocean water?

radiation that penetrates the same area of ocean water also decreases.

How does deep ocean water at the equator compare in temperature with surface water near the poles?

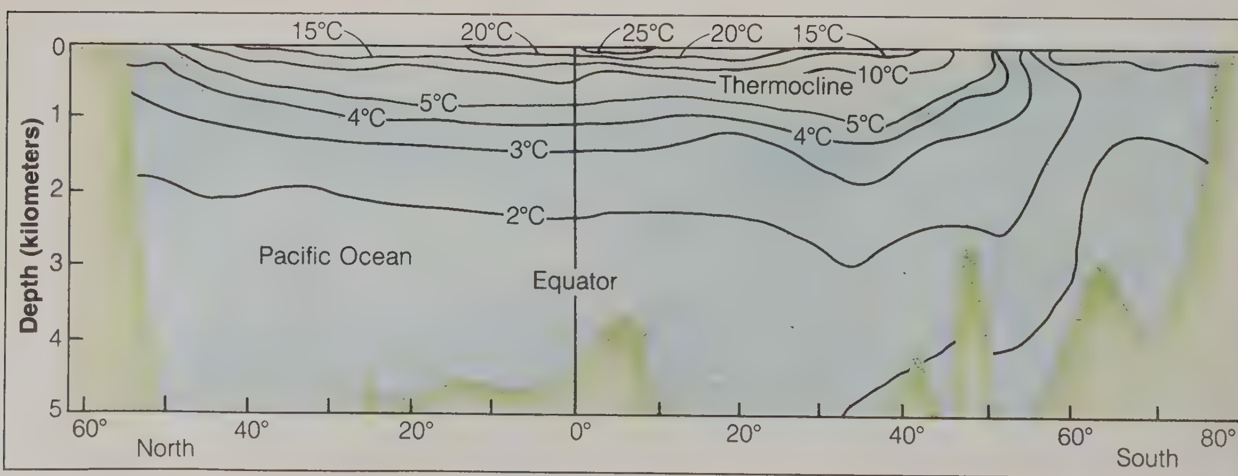
Depth also affects the temperature of ocean water. Figure 8-15 shows the distribution of water temperature with depth from north to south through the Pacific Ocean. You will note that the most rapid temperature changes take place within one kilometer of the surface in the equatorial and temperate regions. Also note that deep ocean water is about the same temperature as the surface water nearer the poles.

Another important property of ocean water is density. As mentioned in Chapter 1, certain materials are more "dense" than others. A certain volume of iron, for example, weighs more than the same volume of wood because the iron has a greater mass and is therefore more dense. Oil "floats" on water because oil is less dense than water.

The density of ocean water depends on the temperature and the salinity of the water. Figure 8-16 shows that as salinity increases, density increases. The density of river water will therefore be less than the density of ocean water since river water is generally understood to be fresh water and therefore contains less dissolved materials than ocean water.

Figure 8-16 also shows that the temperature and density of decreases. As the water temperature rises, for instance, the water becomes less dense. Warmer surface water near the equator is therefore less dense than cooler surface water near the North Pole and South Pole.

Figure 8-15. Where do the most rapid temperature changes in ocean water take place?



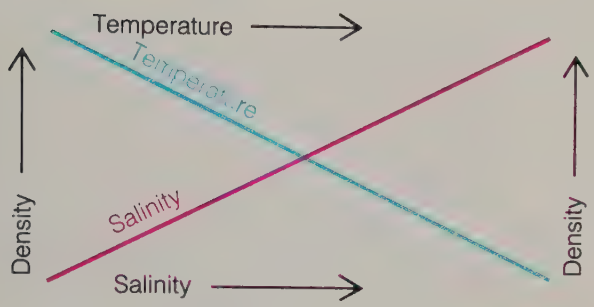


Figure 8-16. As the salinity of ocean water increases, the density also increases. What happens to the density as the temperature increases?

Ocean water moves in large volumes. These large volumes of water are called **water masses.** By determining temperature, salinity, and density, scientists are able to identify large water masses and to trace their movement from place to place.

Check yourself

1. What geographic variables affect the temperature of ocean water?
2. How does temperature affect water density?
3. How does salinity affect water density?

Sea ice

One of the consequences of the temperature, salinity, and density relationship in ocean water is the lack of sea ice in most of the world's oceans. Salinity affects the **freezing point** of water. Pure water freezes at 0°C. Salt water freezes at a lower temperature. The saltier the water is, the colder it must be before it freezes. Water with a salinity of 35 parts per thousand freezes at −1.9°C.

How does the depth of the ocean affect the formation of ice on its surface?

Cooling of ocean water occurs at the surface because of cold winter winds. The spray from winter waves can coat the decks and rails of a ship with ice. And yet, even as ships get coated with ice, the surface of the ocean has no ice. That is because of the relationship between temperature and density. As the surface water gets colder, it becomes denser than the water beneath it. The denser surface water sinks and is replaced by less

Activity Freezing Salt Water

Materials

tap water

graduated cylinder

4 small plastic containers, each with a capacity of at least 250 mL

salt

balance

masking tape or labels

crayons or marking pencil

freezer (at home or at school)

thermometer

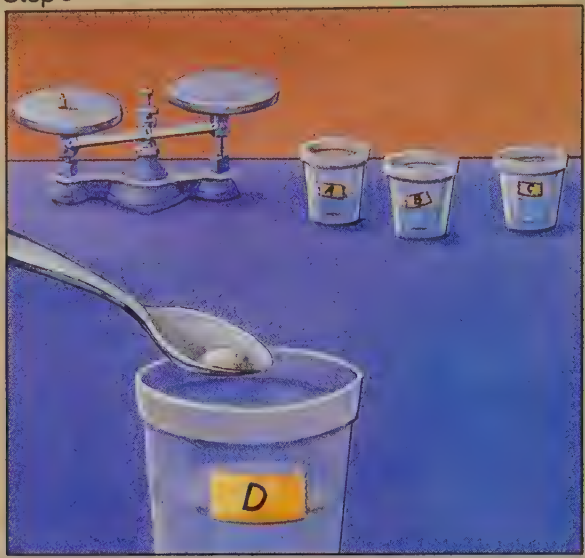
Purpose

To try freezing water of different salinities.

What to Do

1. Using the masking tape and crayon or marking pencil, label one of the plastic containers A. Label the others B, C, and D.
2. Using the graduated cylinder, measure 250 mL of water and pour it into container A. Do the same to the other three containers.
3. Using the balance, measure 3 g of salt and dissolve it in the water in Container B.
4. Measure 6 g of salt and dissolve it in Container C.
5. Measure 9 g of salt and dissolve it in Container D.
6. Assume that the salinity of your tap water is 0 parts per thousand. Calculate the salinity of the solution in Container B, where salinity equals grams of dissolved solids per 1000 mL of water. Record the salinity on the label. Do the same for the solutions in C and D.

Step 5



7. Put your four containers in a freezer, either at home or (if available) at school. At set periods of time, observe the water in each container.
8. When each solution is about half frozen, measure and record the temperature of the solution.

Questions

1. The salinity of ocean water is, on the average, 35 parts per thousand. Which of your containers holds salt water that has a salinity of about 35 parts per thousand?
2. Which solution completely freezes first? Which completely freezes last? What probably causes differences in freezing times?
3. How do the temperatures of the freezing solutions compare? Do all four solutions freeze at the same temperature? If not, which freezes at the lowest temperature?

Conclusion

How can you compare the results of this activity to the freezing of ocean water?

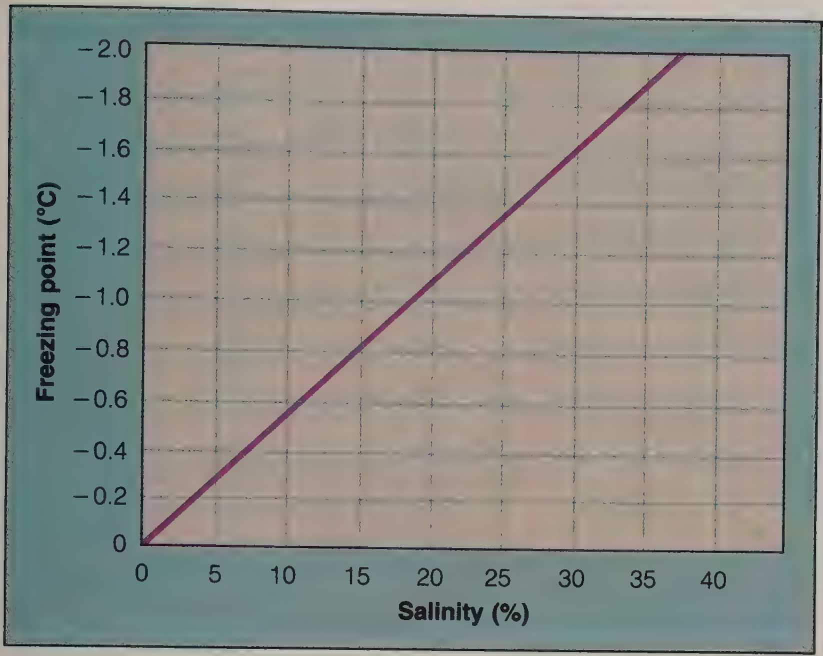


Figure 8-17. This graph shows what happens to the freezing point of water as salinity increases.

dense water, which is not as cold as the water it replaced. As this constant exchange of water continues, the cold water sinking below the surface extends deeper and deeper. This sinking water can be stopped only by the ocean bottom or by a denser water mass.

In the Arctic Ocean, the middle and lower levels have a high-salinity water mass that forms a barrier to the downward mixing of the cold surface waters. The surface water does, therefore, become cold enough to freeze and form **sea ice.** Because of the extreme cold and because of the length of the cold season in the Arctic, the sea ice eventually forms very thick masses called **pack ice.** (See Figure 8-18 on the next page.) Pack ice is ice that has been broken, pushed upward, and refrozen into jagged, irregular ridges known as pressure ridges.

The open Atlantic, Pacific, and Indian Oceans are too deep for sea ice to form. The water never gets cold enough from top to bottom to freeze. However, sea ice might form around the margins of these oceans where the bottom is shallow and where horizontal mixing is restricted. Sea ice might also form in bays and estuaries that have a salinity of less than 24.7 parts per thousand.

Bodies of water with a salinity of less than 24.7 parts per thousand form ice fairly easily during the winter months because such water does not become continuously more dense as it is cooled. The water will reach a maximum density at some

Library research

How does the salt content of sea ice compare with the salt content of the ocean water from which it formed?

Figure 8-18. Pack ice has irregular, jagged ridges. Pack ice is a common sight on Baffin Bay, an arm of the North Atlantic between Greenland and Canada.

Why does water with a salinity of less than 24.7 parts per thousand freeze more readily than saltier water?

temperature above the freezing point. Then, as the water gets colder, it becomes less dense and floats on the surface. This top layer of water gets colder and colder until it freezes. This is the same way that freshwater ponds and lakes freeze.

When you think of ice on the ocean, you might also think of icebergs. **Icebergs,** however, are not sea ice. They are not frozen ocean water. Icebergs are masses of ice that broke off freshwater glaciers that form on the land.

Check yourself

1. Where in the world's oceans does sea ice form?
2. How do icebergs differ from sea ice?
3. How cold must average ocean water be in order to start freezing?

Water pressure

Another physical property of ocean water is **water pressure.** Let's say you are at sea level and standing at the edge of a swimming pool. The atmospheric pressure against your body at sea level, which can be expressed in terms of bars as well as in inches of water or millimeters of mercury, is about one bar. If you dive into the pool and swim to the bottom, you feel an

increase in pressure on your body. As you go deeper below the surface, the water pressure becomes greater. Due to the mass of overlying water, the water pressure increases by one bar for every ten meters depth of water.

Some organisms cannot tolerate large changes in water pressure. For these organisms, water pressure forms barriers which limit vertical movement. The organisms simply cannot live beyond a certain depth because the pressure would be too great for them.

People are also limited by water pressure. Perhaps you have seen a swimmer breathing through a snorkel tube. A snorkel tube permits a swimmer to breathe surface air while swimming facedown on the surface of the water. But all snorkel tubes are very short. It would be impossible for a swimmer one meter below the surface to breathe surface air through a tube because the water pressure would crush the body beyond the ability of the muscles to inflate the lungs.

Figure 8-19. This swimmer is breathing through a snorkel tube. Why is the tube so short?

Divers using air tanks can swim to much greater depths than a snorkler because a regulator delivers the air to the lungs at the same pressure as the water pressure around the diver. This balances the pressure both inside and outside the body, letting the diver's muscles properly inflate the lungs. This same principle of balancing the pressure applies to a person using a diving suit attached to a pressure pump on the surface.

Check yourself

1. What is the rate of pressure change with ocean depth?
2. What is the approximate atmospheric pressure (in bars) at sea level?
3. How are divers with air tanks able to breathe at depths of twenty meters?

Water absorbs light

Sunlight that enters the ocean is a mixture of all the rainbow colors. But pictures taken underwater frequently look blue. Water absorbs light. The blue color is due to the fact that water

absorbs the red, orange, yellow, green, and violet colors of the rainbow spectrum more rapidly than it absorbs blue.

Because water absorbs light, light cannot travel very far through water. In fact, light disappears rather quickly with increasing depth of water. The ocean environment can be divided into three zones, depending on the amount of light that has penetrated to that zone.

The uppermost zone of the open ocean is the zone of most light. This zone extends to a depth of 200 m and is called the **photic zone** (FŌT′-ik ZŌN). (*Photic* is from the Greek word *phōs,* which means a light.) In the upper 150 m of this photic zone, the light is strong enough to support the growth of algae, which are one-celled plants and a basic food source for many animals.

Water between 200 m and 1000 m in depth is quite dark. In this zone, the light is not strong enough to allow algae to con-

Figure 8-20. As depth below the surface increases, divers must use artificial light to observe the surroundings.

Figure 8-21. The angler fish uses bioluminescence to attract other fish. Why is bioluminescence effective below the photic zone of the ocean?

tinue to live. Only a very tiny, almost immeasurable amount of light in the blue color range extends into this zone, which is called the **disphotic zone** (DIS′-FŌT′-ik ZŌN). (*Disphotic* is from the Greek words for half light or reduced light.) Some of the organisms living in the disphotic zone have extremely sensitive eyes. The brightest lights in this zone are produced by animals through a biochemical process called bioluminescence. (Fireflies also produce light by the process of bioluminescence.)

The bulk of the ocean's water lies below the disphotic zone. Except for bioluminescence and underwater lava eruptions, this part of the ocean is in total darkness. Not even the smallest amount of surface light reaches into this zone, which is called the **aphotic zone** (A′-FŌT′-ik ZŌN). (*Aphotic* is from the Greek words for no light.)

Because of the light distribution in the ocean, most organisms are concentrated in the photic zone, where algae live. In the aphotic zone, however, there are some predators and scavengers and "pockets" of life based on a food chain beginning with sulfur-eating bacteria (no photosynthesis involved).

Library research

Prepare a report on planktonic, nektonic, and benthonic sea life forms.

Check yourself

1. What color of light is absorbed least rapidly in water?
2. What are the three major depth zones in the ocean, based on light penetration?
3. What are the natural sources of light in the deep ocean?

Resources of ocean water

Ocean water resources are quite important to people.

□ The bulk of the fishing industry relies on the water over or near the continental margins. Fish are concentrated in these areas because of the greater abundance of smaller organisms and nutrients in the water. Fish are used for food, oils, fertilizer, and livestock feed.

□ Ocean water is 96.5% water. Desalination plants can remove the 3.5% dissolved materials and produce fresh water from ocean water. In some coastal areas, desalination is more economical than other sources of fresh water.

Is desalination an economical way to obtain fresh water?

□ Scientists have been able to find many elements dissolved in ocean water. Although not all elements have yet been detected, many scientists believe that they will eventually be found as better analytical tests are developed. At present, only sodium chloride (table salt), magnesium, and bromine are commonly derived from dissolved elements in ocean water.

□ Differences in water temperature between the surface and the depths can be used to generate electricity. OTEC (Ocean Thermal Energy Conversion) has been tried near Hawaii and offers great promise for the future.

□ Many industries use ocean water as a coolant for their machinery and equipment. The water is circulated through heat exchangers where excess, unwanted heat is absorbed.

□ For recreational purposes, the ocean's waters offer sports fishing, swimming, diving, boating, and water skiing.

□ The ocean provides a habitat for maintaining a great number of different types of life forms. This is ecologically important in order to maintain the quality of life in general and to provide a resource base for future needs. *Pollution* has been responsible for destroying life in the ocean. Offshore oil wells have caused much pollution and destruction of life. Chemical fertilizers are washed down rivers into the ocean. Chemical wastes from factories as well as human sewage have ended up in the ocean.

Check yourself

1. List the seven major resources of ocean water.
2. What substances are presently derived from the dissolved elements in ocean water?

Section 2 Review Chapter 8

Check Your Vocabulary

aphotic zone	photic zone
disphotic zone	salinity
freezing point	sea ice
icebergs	water mass
pack ice	water pressure

Match each term above with the numbered phrase that best describes it.

1. Saltiness; a measure of the amount of total dissolved materials in water; grams of dissolved materials per kilogram of water
2. A large volume of water characterized by a similar temperature, salinity, and density throughout its mass
3. The temperature at which a liquid freezes
4. Frozen ocean water
5. Sea ice that has been broken and then refrozen into jagged pressure ridges
6. Floating masses of ice that broke off freshwater glaciers
7. The force that a mass of overlying water exerts upon a submerged surface
8. The uppermost zone of the open ocean and the zone of most light
9. A zone of reduced light in the ocean; between 200 m and 1000 m deep
10. The part of the ocean that is in total darkness

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The average salinity of ocean water is _?_ parts per thousand.
   a) 16 c) 35
   b) 30.6 d) 38 to 39
2. _?_ are the two most abundant elements that make up the salinity of sea water.
   a) Sodium and potassium
   b) Chlorine and sulfur
   c) Calcium and sulfur
   d) Chlorine and sodium
3. _?_ is the depth zone in the ocean that contains the greatest number of organisms.
   a) Below the photic
   b) Aphotic
   c) Photic
   d) Disphotic
4. The temperature of the ocean below 1 km depth is _?_.
   a) greater than 20 degrees C
   b) 15 to 20 degrees C
   c) 5 to 10 degrees C
   d) less than 5 degrees C
5. The pressure at 100 meters depth in the ocean is _?_ bars.
   a) 101 c) 11
   b) 100 d) 10

Check Your Understanding

1. Ocean water is a saline solution. Explain.
2. What factors affect the formation of ice on these bodies of water—a pond, a deep lake, a river, an ocean?
3. What are two causes for increases in the temperature of ocean water? Where does each kind of heating occur?
4. How is life in the ocean affected by light?
5. How does water pressure affect life in the ocean?

The Circulation of Ocean Water Section 3

Section 3 of Chapter 8 is divided into six parts:

Directions of motion in a wave

The beginning, middle, and end of a wave

Effects of wave action

Tides

Surface ocean currents

Deep ocean circulation

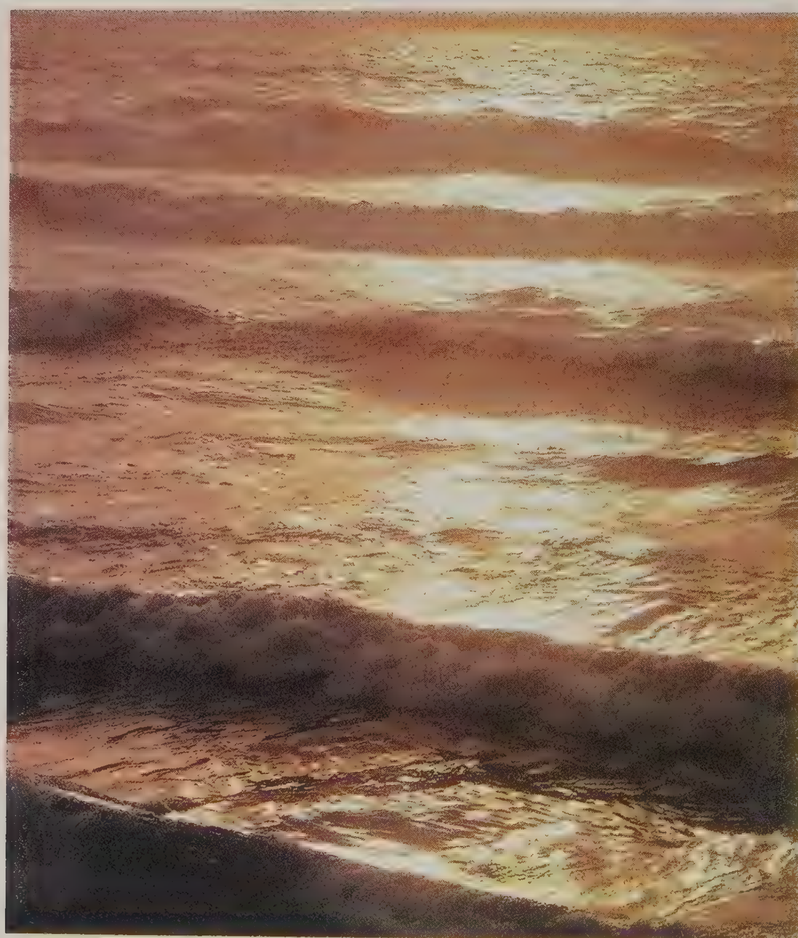


Figure 8-22. It is afternoon as these waves approach San Francisco's Ocean Beach. What evidence suggests these waves are approaching a beach?

The ocean's water is like a restless person, shifting from place to place and always on the move. Some of the ocean's water moves in and out of the ocean through evaporation and precipitation. But most of the ocean's water simply moves around within the ocean environment.

How is the ocean's water like a restless person?

Waves, tides, and currents are three major ways in which ocean water moves. The ways in which ocean water moves, the forces that cause these movements, and the effects of ocean water movements are of particular interest.

Directions of motion in a wave

If you've ever tried floating among waves, you are familiar with at least two directions of motion that are caused by waves. One direction of motion is up and down. As waves pass under you, they cause you to bob up and down.

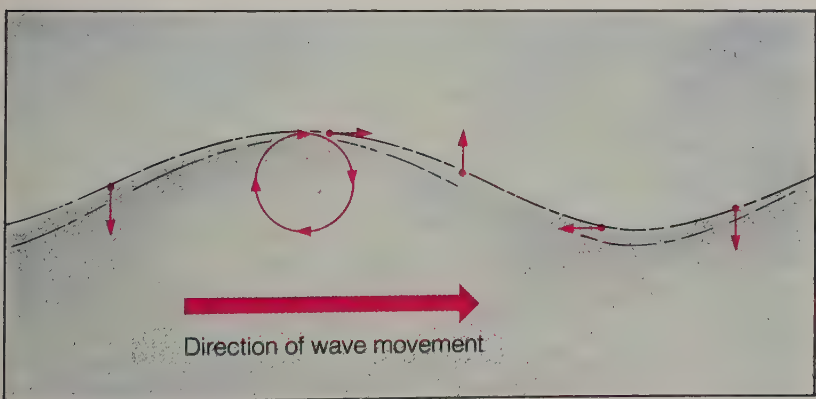


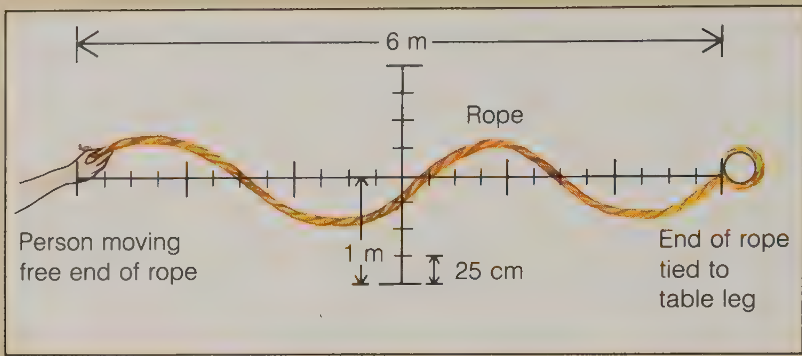
Figure 8-23. The small arrows show directions of motion caused by wave movement. What are four directions of motion in a wave?

Another direction of wave motion is forward and backward. If you are floating near the shore, waves will generally push you toward the shore. It is this same directional movement that causes driftwood and other debris to wash up onto the shore.

What causes driftwood to wash up onto the shore?

The combination of up, down, forward, and backward is shown in Figure 8-23. This combination produces an orbital motion. As a wave moves, the water in the wave does not stream forward with the wave. The water moves in an orbit as the waves pass by.

Activity Simulating Wave Motion



Materials

6.5-m length of small-diameter rope

chalk

meter stick

graph paper

colored pencils

plastic foam ball, 2-3 cm diameter, with hole large enough for rope to pass through

Purpose

To use a rope to imitate the motion of a wave.

What to Do

1. Working in a group of two or three students, attach one end of the rope to the leg of a chair or table. Pull the rope out straight.
2. On the floor, draw a simple grid similar to the one shown in the diagram. Use chalk and a meter stick, with the outstretched rope as a guide.
3. On a piece of graph paper, make a grid that represents the one on the floor.
4. One student should wiggle the free end of the rope from side to side to make waves.
5. The other students in each group should observe and estimate the direction, the height, and the length of the waves. During these measurements, the student making the waves should maintain a constant amount of motion in the rope.
6. On the graph paper, plot a wave that represents (in height and length) the wave you observed. With an arrow, indicate the direction of motion.
7. Now vary the speed of the waves. The student moving the rope should move the free end either faster or slower but should keep his or her hand moving the same distance from side to side.
8. Once a different speed has been established, another set of measurements should be estimated and recorded. Plot one of these waves on the graph, using a different color line for this wave.
9. Now fasten the plastic foam ball to the center of the rope. First, tie a simple knot about halfway down the rope. Then thread the free end of the rope through the hole in the ball and move the ball along the rope to the knot. Tie a second knot on the other side of the ball to hold the ball in place.
10. Wiggle the end of the rope to set up a wave motion.

Questions

1. What is the relationship between the speed of the wave and the speed of the side-to-side motion of the hand?
2. What would need to be done to make higher waves?
3. How does the ball's motion differ from the wave's motion?
4. How does the size of the ball's movement compare with the wave height?

Conclusion

How might the answer to these last two questions be plotted on a graph? Try it.

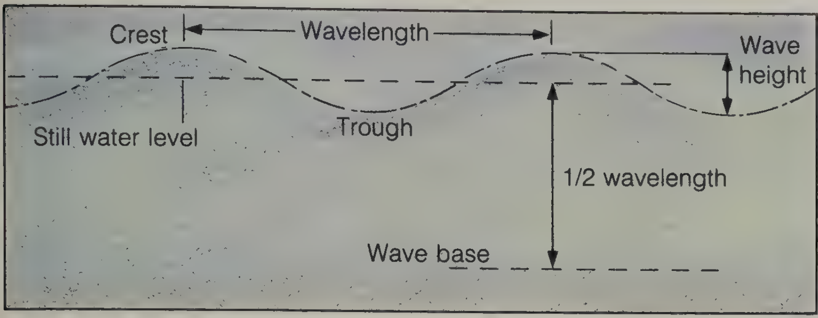


Figure 8-24. What is the relationship between wave base and wavelength?

Look for a minute at Figure 8-24 and familiarize yourself with the names of various parts of a wave. The **crest** of a wave is its highest point. The **trough** is the lowest point between two wave crests. **Wave height** is the vertical distance between a wave's highest and lowest points. **Wavelength** is the horizontal distance from a point on one wave to the corresponding point on the next wave. And **wave base** can, as a general rule, be located at a depth of one half a wavelength below the mid-height of the wave.

As shown in Figure 8-23, the orbit at the surface is circular and has a diameter that is equal to the wave height. As depth below the surface increases, the diameter of the orbit becomes increasingly smaller until, at a depth called the wave base, the size of the orbit is only one twenty-third of the diameter at the

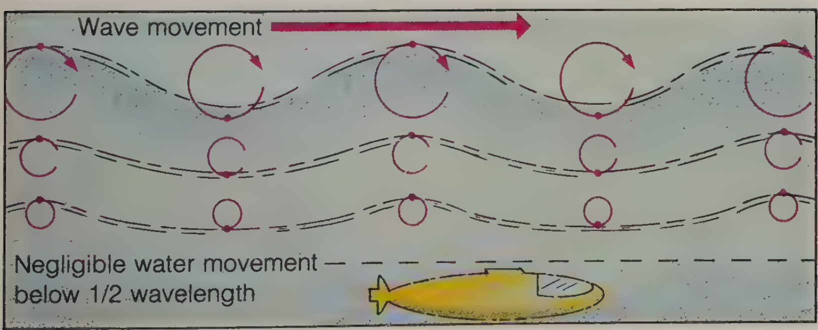


Figure 8-25. How deep must a submarine be in order to escape the orbital motion of surface waves?

surface. At wave base, the orbital motion of a wave nearly disappears. A submarine located below wave base will not be affected by the orbital motion of water due to surface waves.

Check yourself

1. Draw and label a profile view of a wave.
2. Using arrows, show the direction(s) of movement of the water in the wave you drew.

The beginning, middle, and end of a wave

Why do ships have a difficult time during a storm at sea?

Many ocean waves begin in a state of total confusion. They form in a storm area and are caused by the winds associated with the storm. The water surface under a storm center at sea has a very irregular pattern of waves. Waves of many different heights and lengths are formed by the winds within the storm center. Some of the waves exceed a height-to-length ratio of 1 to 7 and collapse. Other waves interact with each other to make the surface of the ocean even more confused. Because of irregular wave sizes and patterns and because waves are breaking and interacting on the surface of the ocean, ships have a very difficult time during a storm at sea.

Waves transmit energy. The energy transmitted across the surface of a stormy area at sea is very irregular because the energy in a wave is related to its height. To be specific, wave energy is directly proportional to the square of the wave height. A wave two meters high has four times as much energy as a wave one meter high. A wave six meters high has thirty-six times as much energy as a wave one meter high. In other words, it takes about thirty-six times as much wind energy to form a six-meter wave as to form a one-meter wave.

Figure 8-26. A storm causes hazardous conditions for this fishing boat off the coast of Scotland.

Careers Marine Geologist / Computer Operator

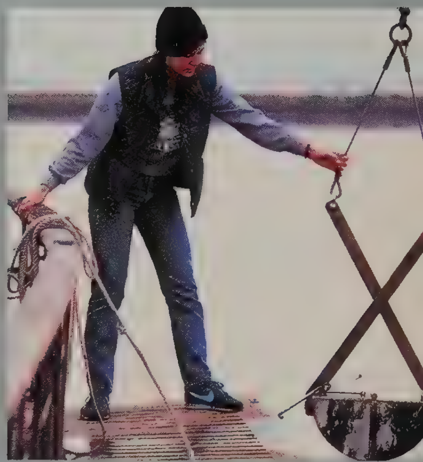
Marine Geologist Marine geology is the study of the rocks and land under the ocean. It is a branch of oceanography, which also includes the study of biological, physical, and chemical aspects of the ocean.

Some marine geologists do research that is designed to increase our basic knowledge about underwater land. Some seek information about fossil fuels. Others work to find underwater mineral deposits.

Some oceanographic work is done in offices and laboratories, but much experimentation and data-gathering are done at sea. Some marine scientists use scuba gear and other underwater equipment in their work.

Approximately half of all oceanographers in the United States and Canada are employed by universities. Many others work for government agencies.

It takes many years of study to become an oceanographer. If you want to specialize in marine geology, a college degree in geology and graduate courses/study in oceanography probably would provide the best training. You will be likely to spend some of your time aboard a research ship while you are a graduate student.



Marine geologists can tell much from sediments scooped up from under the sea.

Computer Operator Computer operators (or console operators) follow written instructions to set up and run jobs on large computers.

The operator loads the program, or instructions to the computer, and the data to be processed. The program and data, which are called input, may be on punch cards or magnetic tapes or disks.

The operator then monitors the computer while it is running. If the computer stops in the middle of a program, or if an error light goes on, the operator tries to identify and solve the problem. It is important for operators to be able to solve problems because many operators work at night when other employees are not available to help them.

If you enjoy following step-by-step procedures, making decisions, and working independently, you might like to be a computer operator. There are a variety of ways to prepare for this career. Some high schools offer courses in computer operating. High school graduates can learn needed skills at two-year colleges, computer schools, and in the armed forces.

This computer operator operates a group of computers that control a circular accelerator at the Berkeley Radiation Laboratory.

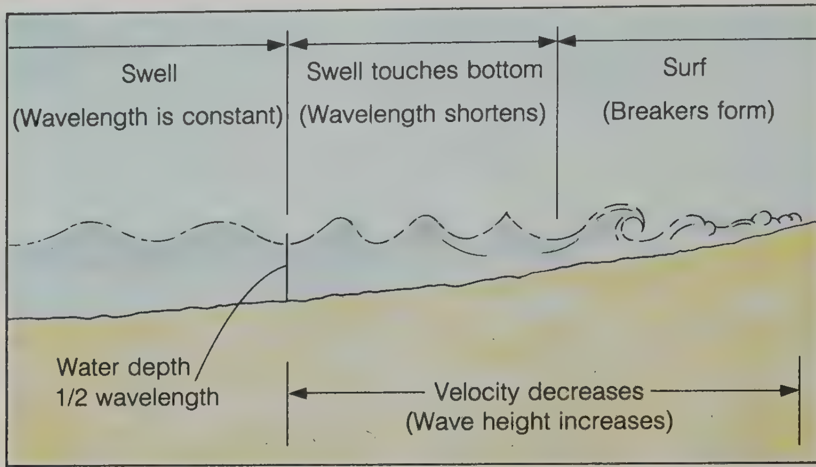


Figure 8-27. What happens to a wave as it nears the shore?

The middle stage of a wave is much more regular than its beginning. As waves move away from a storm center, they separate according to wavelength. This happens because waves with long wavelengths travel faster than waves with short wavelengths. Eventually a regular rhythmic pattern of waves develops. This regular pattern of waves of similar wavelength is called **swell.**

Library research

Where in the world do the best waves for surfing occur? Why do these waves occur in those locations? What features cause surfers to desire these waves?

Ocean swell can cover hundreds of kilometers of open ocean, with the waves all moving forward without breaking or collapsing. The orbital motion within the waves of ocean swell is circular. The energy in ocean swell is transmitted across the ocean with very little loss.

Most waves eventually end up on a beach. As ocean swell nears the shore, the water becomes shallower. Where the ocean bottom is above wave base, the orbital motion of the water in waves changes from circular to elliptical. As the water continues to become shallower, the elliptical orbit becomes flatter. At the same time, the wavelength shortens and the wave height increases until the wave can no longer maintain its shape. At this point the wave collapses, either as a foaming mass of water or as a forward-breaking mass of water. The area near the ocean's margins where breaking waves occur is called the **surf zone**.

Check yourself

1. List the three stages a wave can go through.
2. What aspect of wave motion is responsible for the development of swell?
3. What force in nature creates most ocean waves?

Effects of wave action

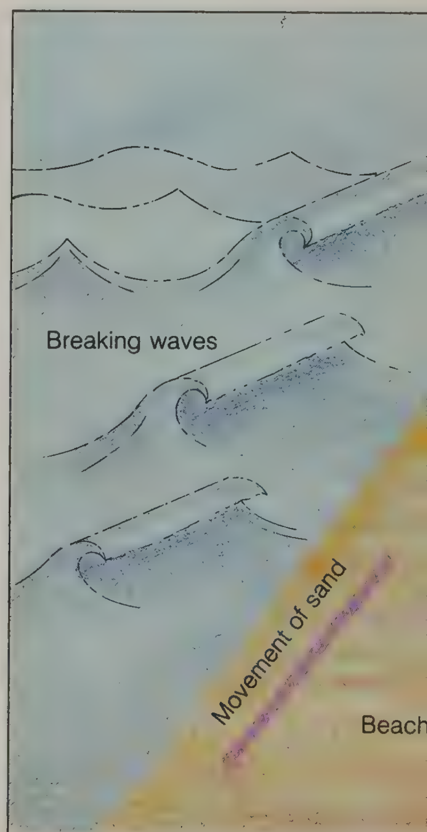
On the open sea, storms can create huge breaking waves and irregular wave patterns that are dangerous to ships and to other surface objects such as offshore oil-drilling rigs. In addition to the waves of stormy seas, there are also huge waves that form as the result of wave interference. Wave shapes are additive. When the swells from different storm centers pass through the same water and the crests and troughs coincide, a single crest forms that is equal in height to the sum of the two original crests.

Can waves combine to form larger waves?

When two or more high waves of about the same wavelength have their crests coincide, the resultant wave, which is called a **rogue wave**, is usually big enough to cause problems for ships. Rogue waves can form and disappear very quickly. The southeastern coast of Africa is known for fairly frequent rogue waves. Many ships have been lost or damaged because of these waves which develop heights up to twenty meters.

Along the margins of the oceans, waves can directly attack the land. The constant pounding of waves can, over long periods of time, reduce boulders and rocky cliffs to particles of gravel and sand. Waves not only directly attack the shore, but they create a movement of loose particles and water in the surf and on the beach. As shown in Figure 8-28, waves approach the shore diagonally, which causes a zigzag motion of water along the shore. The result of this zigzag motion is the movement of sand along a coastline. The sand may be moved hundreds of kilometers. If the supply of sand from rivers and eroding sea cliffs were to stop, then most of the sand beaches would eventually disappear.

Figure 8-28. How does the angle at which these waves approach the beach affect the sand along the coastline?



Along the Pacific coast of North America, the beaches would all disappear fairly quickly if the sand supply ended.This coastline has a narrow continental shelf. In a few places, submarine canyons cut across the shelf and come fairly close to the shore. The sand that is moving along the shore slips down into these submarine canyons and drains onto the ocean bottom.

Perhaps the most rapid damage to a shoreline is caused by a huge wave called a **tsunami** (tsoo-NAH′-mee). A tsunami is actually a group of waves with fourteen or more crests and is caused by an underwater earthquake somewhere along the

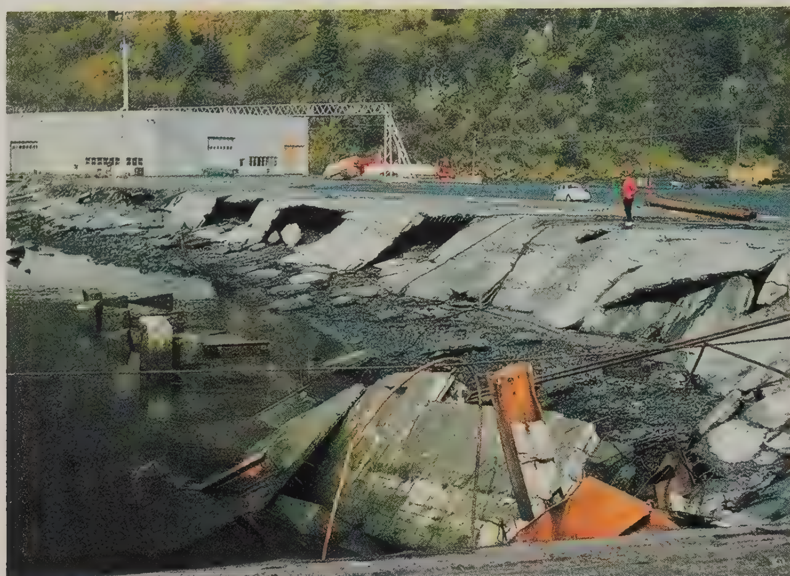


Figure 8-29. This destruction at Seward, Alaska, was caused by a group of huge waves called a tsunami. What causes a tsunami?

ocean bottom. At sea, the waves of a tsunami may have a height of only 2 m and a wavelength of up to 160 km. Because of their wavelength, it can take up to 15 minutes for successive wave crests to pass a given point on the surface of the ocean even though they may be traveling more than 600 km per hour. And because of their height-to-length ratio, these waves are scarcely noticeable out at sea.

But as the waves of a tsunami approach the shore and the water becomes shallower, they can build to a height of 50 m. A moving wall of water this high can toss railroad locomotives around like toys. Buildings can be smashed. Trees can be snapped like toothpicks. Whole villages and cities can be wiped out by a tsunami. Tsunami are most common around the margins of the Pacific Ocean because of the large number of earthquakes that are associated with that area.

Check yourself

1. If a ship traveling in a nine-meter swell were hit by a rogue wave, how high might the wave be?
2. Where are tsunami destructive?
3. What causes rogue waves?

Tides

If you've ever built a sand castle on an ocean beach, you've probably noticed that over a period of time the waterline moves either toward the castle or away from the castle. This happens because the level of the sea at a particular location rises and falls during the course of a day.

About once every twelve hours, the waterline reaches what can be called the high water mark. When the waterline reaches this level, the ocean at that location is said to be at **high tide**.

After the waterline reaches the high water mark, the waterline then moves back down toward the open sea until it reaches a low water mark. When the waterline reaches its lowest point, the level of the sea in that area is at **low tide**.

High tide is the result of huge bulges in the level of the ocean. The bulges are caused mainly by the moon and the movement of the earth and moon. Figure 8-30 shows the bulges in sea level in relation to the position of the moon.

You will notice that there are actually two bulges. The one nearest the moon is caused by the force of gravity from the moon attracting objects on the earth's surface. The moon pulls on all parts of the earth. But the pull is strongest at the points closest to the moon. The earth's solid surface is not greatly affected by the moon's gravitational pull. But the water on the earth's surface is noticeably affected because water is fluid and can change its shape. The bulge directly opposite the moon, on the other side of the earth, is caused by the rotation of the earth and moon through space.

The fact that sea level at any location goes from high tide to low tide and back again is due to the earth rotating on its axis. The solid earth is actually rotating under the bulges of water.

Tides affect the kinds of plants and animals that can live along the margins of the oceans. Tides can cause alternate wetting and drying of land areas. Rising and falling tides create tidal currents in coastline environments. Incoming tidal currents can bring salt water into an area that has fresher water at low tide. Incoming and outgoing tidal currents also affect the temperature of an environment.

Tides also affect people who live, work, or travel near the water's edge. Tidal changes affect the depth and the water

Figure 8-30. How does the moon affect the level of the ocean's surface on the earth?

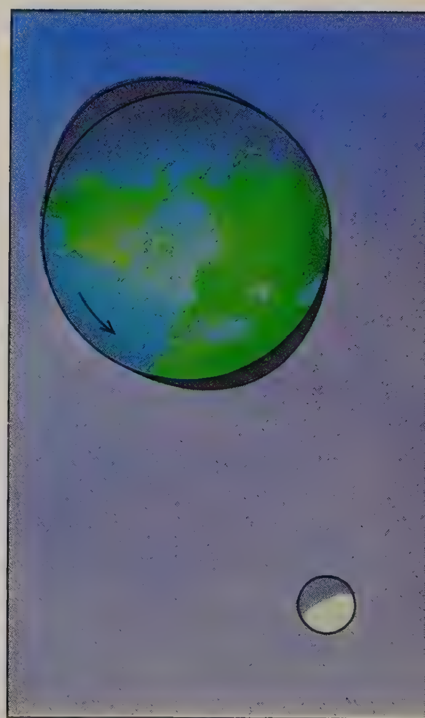


Figure 8-31. Parrsboro, Nova Scotia, is located on the Bay of Fundy, where tidal differences are extraordinary.

speed and direction in harbors and along coastlines. For that reason, ships frequently schedule their arrivals and departures to coincide with a certain tidal condition. Other nearshore and offshore activities, such as fishing and recreation, are also affected by tides.

Several factors affect the timing and the height or strength of tides.

1. Tides do not occur on a 12-hour schedule because the moon orbits the earth at a speed that is slightly faster than the earth's rotation. It therefore takes about 12 hours and 25 minutes for two successive high tides to pass the same location.

2. The shape of the ocean basins affects the timing of the tide. In some places (for example, parts of the Gulf of Mexico), the bulge opposite the moon is not developed. In that case, the cycle from high water to high water takes 24 hours and 50 minutes.

3. The shape of a shoreline affects the strength of the tide. The tides are usually weaker at the mouth (the wide end) of a V-shaped bay than at the head (the narrow end of the bay).

4. The sun's gravitational force also affects the tides. Twice a month, during full moon and new moon, stronger tides with higher and lower water can occur because of the relative positions of the sun, moon, and earth with respect to each other.

Library research

What conditions make cliff-diving at Acapulco such a thrilling sight to see? Why is the timing of the divers so very important?

5. Local storms may also affect the timing and the strength of the tides along a coastal area.

With the exception of the effects of storms, the times at which high and low tides will occur at a given location can be predicted accurately if the history and characteristics of that location are known. Because of the number of variables, predictions are most easily made by using computers.

Why are computers useful in making tidal predictions?

Check yourself

1. What is the tide?
2. How much time does it take to go from high tide to high tide?
3. How can the tides affect people's activities?
4. What types of information are needed in order to make tidal predictions?

Surface ocean currents

Ocean water circulates from place to place at rates much slower than the movement of waves or tides. Oceanic circulation, although slow, moves unbelievably large quantities of water. The Antarctic Current, for example, moves about 190 times more water than all the freshwater rivers and streams on the earth.

How much water moves in the Antarctic Current?

The circulation of surface ocean water is caused primarily by the interaction of four phenomena: the wind, the Coriolis effect, the pull of gravity, and the position of the continents. Figure 8-32 shows the major patterns of water circulation on the ocean's surface.

Both wind and water tend to move in a constant direction. The earth beneath them, however, rotates. Therefore, the path of objects moving across the earth's surface appears to change. The rotation of the earth causes both atmospheric winds and ocean currents to turn to the right of their paths of motion in the Northern Hemisphere and to the left of their paths of motion in the Southern Hemisphere. This deflection of objects moving across the earth's surface is known, as you may recall, as the Coriolis effect.

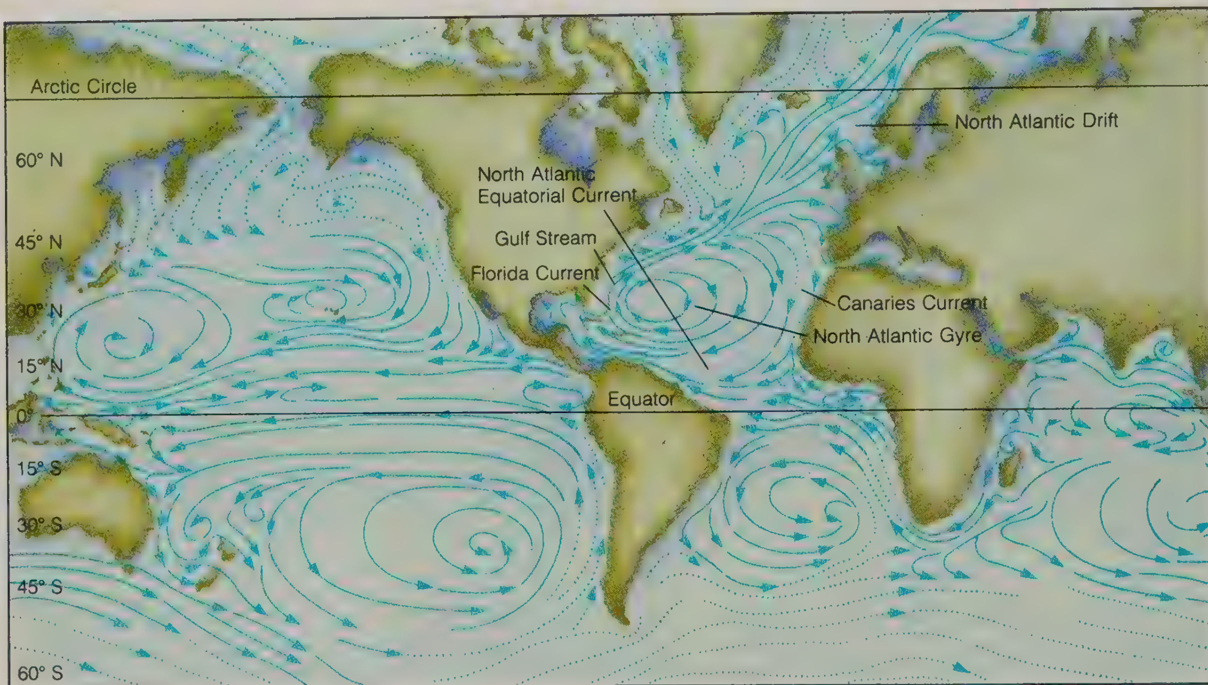


Figure 8-32. This map shows the ocean's major circulation patterns.

Consider for a moment the currents in the Pacific or Atlantic Ocean. Prevailing winds cause east-west movements of water that are forced to flow north-south at the margins of the ocean basins. Several major rotating systems of currents are formed in this way. Each of these closed systems of rotating currents is called a **gyre** (JĪR), from the Greek work *guros,* which means a ring or a circle. As an example, look at the North Atlantic Gyre located to the east of Florida on the map above.

The Coriolis effect causes clockwise gyres in the oceans of the Northern Hemisphere and counterclockwise gyres in the oceans of the Southern Hemisphere. (See Figure 8-32.) Between gyres, part of the water on the western edge of the oceans returns across the oceans as an equatorial countercurrent. When this water reaches the eastern side of the ocean basin, it moves north and south and is fed back into the low latitude parts of the gyres.

Each of the gyres is made up of several ocean currents. As shown in Figure 8-32, the gyre in the North Atlantic contains the Florida Current, Gulf Stream, North Atlantic Drift, Canaries Current, and North Atlantic Equatorial Current.

Currents within a gyre can be recognized by their physical properties. The Florida Current, for example, is a narrow, well-defined, fairly strong current in which warm waters are moving north into cooler water. The Gulf Stream carries warm water northeast from the Florida Current into the North Atlantic, where the current starts to fan out.

As the water moves across the ocean in the North Atlantic Drift, it is constantly being cooled. It is also becoming a wider, slower current. By the time the water reaches the eastern side of the ocean basin, it has spread out and slowed down so much that the Canaries Current has no well-defined margins.

How does water change as it moves in the North Atlantic Drift?

Surface ocean currents affect the climate of coastal areas. In general, ocean currents flowing from the equator contain warm water. The warm water warms the air which in turn increases air temperatures along the coast. Ocean currents flowing toward the equator generally carry cool water, which has a cooling effect on air temperatures.

Ocean currents affect climate in another way as well, because as ocean currents affect air temperature, they also affect the moisture content of the air. Warm air that blows from the ocean over the land brings not only warmer temperatures but also moisture.

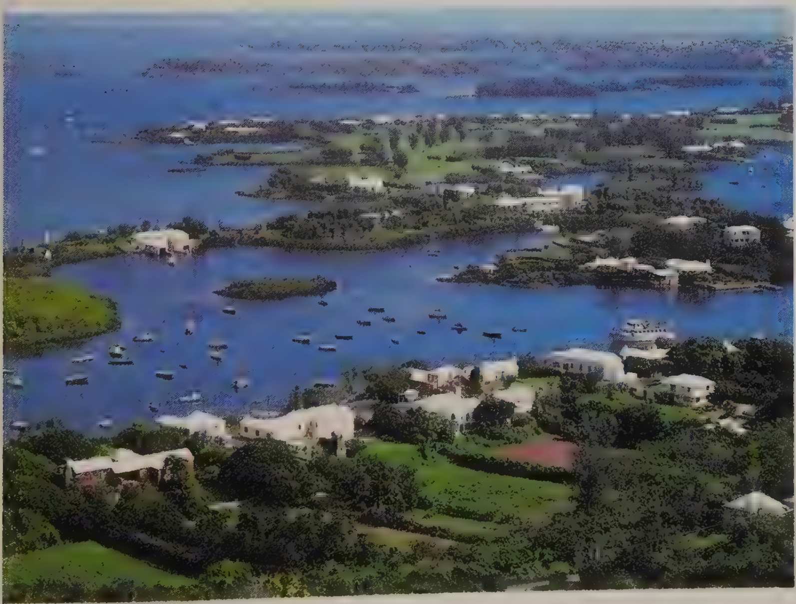


Figure 8-33. The climate of Little Sound, Bermuda, is affected by an ocean current flowing from the equator. What effect do such currents generally have on air temperatures?

As an example, minor shifts in the position of the Gulf Stream that persist over several months can be correlated with either severe winters or mild winters in Europe, depending on the direction of the shift. In North America, weather patterns are likewise affected by the position of the Japanese Current in the North Pacific Ocean.

Check yourself

1. What are the four factors that cause the surface circulation in the ocean?
2. Describe the currents in the major North Atlantic gyre.
3. What effects do the gyre systems have on temperature and climate?

Deep ocean circulation

Deep ocean water also circulates in definite patterns. Most of this circulation is caused by colder polar water sinking. This sinking water contains dissolved oxygen, which is extremely important to the animals living in the deep ocean.

After sinking, the cold oxygen-rich waters travel toward the equator. The earth's rotation causes the water to follow the western edges of the ocean basins. The water eventually moves eastward across the ocean basins. It will return to the surface only near continental margins where prevailing winds push less dense surface waters away from the shoreline. Where this type of wind-caused water movement takes place over long distances of shoreline, the deeper water must rise to fill in behind the outgoing surface waters. This process by which deep, cold water comes to the surface is called **upwelling.**

In areas of upwelling, nutrients from the deep ocean are brought to the surface. As excrement and dead organisms settle from the surface to the bottom of the ocean, bacteria convert the organic matter back into a dissolved form. The dissolved matter includes the nutrients phosphorus and nitrogen. These nutrients become concentrated in deep ocean water. In

Figure 8-34. Why are some of the world's major fisheries located in areas of upwelling?

areas of upwelling, these nutrients are brought to the surface where plants and animals can use them. That is why some of the world's major fisheries are located in areas of upwelling.

Check yourself

1. What causes circulation in the deeper ocean waters?
2. Describe the transfer of dissolved nutrients both to and from the deep ocean basins.
3. Describe the circulation pattern of the deep ocean waters.

Activity Simulating Effects of Heat Absorption on the Earth's Surface

Materials

timer (or clock or watch that indicates seconds)
thermometer (quick-response type preferred)
heat lamp
dishpan or similar container
light-colored sand
dark-colored sand
water
long-handled wooden or plastic spoon for stirring

Purpose

To compare the absorption of heat by different materials.

What to Do

1. Make four data tables that begin like the one shown (for light-colored sand, dark-colored sand, still water, and moving water). Extend each to include three depths: 1 cm, 3 cm, and 5 cm below the surface.
2. Pour light-colored sand into the container to a depth of at least 6 cm.
3. Place the heat lamp so that the heat source is about 20 cm above the surface of the light-colored sand. Measure the distance between the light and the sand's surface. (Maintain this distance for each material.)
4. Before turning on the lamp, take temperature readings of the sand at depths of 1 cm, 3 cm, and 5 cm. Record these readings in the appropriate spaces on your data table for light-colored sand.
5. Turn on the heat lamp. SAFETY NOTE: *Have dry hands when you turn on the lamp. Do not touch the heat source once the lamp is on. Turn off the lamp whenever it is not needed.*
6. At the end of 2, 4, and 8 minutes of heating, take the necessary temperature readings. Record them on your data table.
7. With the heat lamp off, empty the light-colored sand from the container, replace it with dark-colored sand, and repeat the experiment.
8. Repeat the experiment, this time for still water. SAFETY NOTE: *When using an electrical appliance near water, care must be taken to keep water from touching the appliance or its cord. Also, the person turning the appliance on and off must have dry hands.* Measure and record the temperatures.
9. For the moving-water experiment, refill the container with fresh water before taking the first temperature reading. Then, using the spoon, create a water circulation by continually stirring the water or by making waves on the surface. Continue this motion until the table has been completed.

Questions

1. Which material can absorb the most energy with the least change in temperature?
2. How does the color of a substance affect the absorption of heat?
3. How does depth affect temperature?

Conclusion

How does motion in the water affect the distribution of heat? Why?

Data Table for Light-colored Sand				
Depth of Temperature Reading	Temperature Before Lamp Is Turned On	Temperature With Lamp On for 2 Minutes	Temperature With Lamp On for 4 Minutes	Temperature With Lamp On for 8 Minutes

Section 3 Review Chapter 8

Check Your Vocabulary

crest	trough
gyre	tsunami
high tide	upwelling
low tide	wave base
rogue wave	wave height
surf zone	wavelength
swell	

Match each term above with the numbered phrase that best describes it.

1. The highest point of a wave
2. The lowest point between two wave crests
3. The vertical distance between a wave's highest and lowest points
4. The horizontal distance from a point on one wave to the corresponding point on the next wave
5. The point below the surface of water at which the orbital motion of a wave nearly disappears (1/2 a wavelength below the mid-height of the wave)
6. A rhythmic pattern of waves
7. The area where breaking waves occur
8. A very high wave that forms on the open ocean when high waves of about the same wavelength have their crests coincide
9. A huge wave caused by an underwater earthquake somewhere along the ocean bottom; barely noticeable out at sea
10. When the waterline of a body of water reaches its highest point
11. When the waterline of a body of water reaches its lowest point
12. A closed system of rotating ocean currents
13. A process by which deep, cold, nutrient-rich water is brought to the surface and replaces lighter surface water

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The orbital motion of a wave is greatest (largest diameter) _?_.
   a) at wave base
   b) about ½ the depth of wave base
   c) below the trough but above wave base
   d) at the surface
2. The energy in a wave is proportional to _?_.
   a) wave height squared
   b) wave length squared
   c) wave speed squared
   d) wave length
3. Tsunami are caused by _?_.
   a) wind
   b) coinciding crests of two or more different waves of about the same wavelength
   c) underwater earthquakes
   d) density differences in the water
4. The tide is caused by _?_.
   a) wind
   b) the moon's gravitational pull
   c) the rotation of the earth
   d) the moon's gravitational pull and the earth's rotation

Check Your Understanding

1. What happens to the movement of water in a wave in the surf zone?
2. How does the height-to-length ratio of waves change when they merge to form a rogue wave?
3. How is sand moved along a coastline?
4. Describe the factors that affect the timing and height (strength) of tides.
5. How do the major gyres of rotating ocean surface currents differ in the Northern and Southern Hemispheres?

Chapter 8 Review

Concept Summary

Oceans and seas cover nearly 71% of the earth's surface.

- ☐ The oceans are the Pacific, Atlantic, Indian, and Arctic.
- ☐ Marginal seas form in three different ways.
- ☐ The depth of the oceans is measured by echo sounding.

The **ocean bottom** has a varied topography.

- ☐ Continental margins connect the continents with the deep ocean basin.
- ☐ The mid-ocean ridge is a continuous feature that girdles the entire surface of the earth.
- ☐ The varied topography is formed from volcanic activity, erosion, and deposition of sediments. Ocean bottom resources are extremely varied and of great value.

Physical properties of ocean water affect the ocean environment.

- ☐ The salinity of sea water varies from place to place in the oceans, but the average is 35 parts per thousand.
- ☐ Surface temperatures are highly variable, but vary only slightly (from 5°C to less than −1°C) below 1 km depth.
- ☐ Density in ocean water varies as temperature and salinity change.
- ☐ Water pressure increases 1 bar every 10 meters depth.
- ☐ The ocean depths can be divided into three zones (photic, disphotic, and aphotic) on the basis of available light.

Ocean water movements affect the ocean environment, the coastline, and the climate.

- ☐ Water motion in most waves (which are created mainly by storms and other winds) is circular rather than forward.
- ☐ The rhythmic rise and fall of tides is created by the gravitational pull of the moon and the rotation of the earth.
- ☐ Ocean surface currents form large circular motions called gyres.
- ☐ Deep water circulation is caused by the sinking of cold water near the poles.
- ☐ Upwelling returns deep, cold, nutrient-rich water to the ocean's surface.

Putting It All Together

1. Describe the ocean environment at 3000 m depth. Include all physical and chemical features.
2. How do deep ocean currents differ from surface currents?
3. What causes changes (increases and decreases) in the ocean's salinity?
4. Do increases in salinity and temperature affect water density in the same way? Explain your answer.
5. How does water pressure affect people's activities in the ocean?
6. Describe the topographic features in the ocean.
7. Describe the effects of waves and tides on a shoreline.
8. Explain why sea ice is able to form in the Arctic Ocean.
9. Describe the formation and movement of a tsunami. Include places where one is most likely to occur.
10. How are marginal seas related to structural features of the ocean bottom?

Apply Your Knowledge

1. What types of ocean resources seem to be at cross purposes in terms of their use or development?
2. Explain how a vessel could travel across the ocean and not feel the orbital motion of the waves.
3. How might the topography of the ocean basins affect deep ocean circulation?

4. How could a captain wisely use surface current information while engaging in commercial shipping between Europe and North America?
5. What percentage of meteorites striking the earth's surface would probably end up on the ocean bottom? Explain your answer.

Find Out on Your Own

1. Using reference books, find out how OTEC works, and make a labelled diagram of an OTEC system.
2. Where in the world are the major areas of upwelling and what percentages of the world's fish catch is taken from these waters?
3. Describe the major surface gyres in all the oceans. How do the currents in these gyres compare and contrast? What types of patterns are present?
4. Make a detailed list of all the products made from menhaden (Atlantic herring).
5. What are some of the hazards for divers using air tanks?
6. What are the bends? What causes them? What can be done for a victim of the bends?
7. Find out specifics about a recent deep-sea expedition and report your findings to the class. Some possibilities: the Mariana Trench, the underwater canyon in Monterey Bay (California), the Red Sea, the Mid-Atlantic rift zone, the search for the *Titanic* or some other sunken vessel.

Reading Further

Cook, Jan Leslie. *The Mysterious Undersea World*. Washington, DC: National Geographic Society, 1980.

Beautiful color photography and descriptive text of the undersea world.

Davis, Richard A., Jr. *Principles of Oceanography*. Reading, Massachusetts: Addison-Wesley Publishing Company, Inc., 1972.

A college-level text that is clearly written and well illustrated. As a reference, Davis's book will help you to understand better many of the earth processes mentioned in your earth science text.

Elting, Mary. *Mysterious Seas*. New York; Grosset and Dunlap, 1983.

An interesting, informative book about little-known facts of life in the oceans. The section on unsolved mysteries connected with the undersea world is especially appealing. Fine illustrations, glossary, index, and pronunciation guide—all useful learning aids.

Hargreaves, Pat (Ed.). *The Arctic*. Morristown, NJ: Silver Burdett, 1981.

Each chapter describes one aspect of the ocean: waves, tides, winds, currents, continental drift. The book also describes the interaction of humans with the ocean.

Heezen, Bruce C., and Charles D. Hollister. *The Face of the Deep*. New York: Oxford University Press, 1971.

An illustrated natural history of the deep-sea floor. Hundreds of close-up photographs of tracks, traces, and organisms of the abyss. A wonderful book to browse through.

Lambert, David. *The Oceans*. New York: Warwick, 1980.

An excellent book on the marine world. Topics include harnessing wave energy, endangered oceans, hydroelectric power.

Wenzel, Hein. *The Eternal Sea*. Translated by Walter Kaufman. London: Abelard-Schuman, 1970.

A pictorial anthology of seas, seacoasts, and sea-related people and animals around the world. Interesting, short, descriptive passages enhance photographs of exceptional quality.

Science Issues of Today Aquaculture to Help Meet the World's Hunger

Fish and shellfish, both marine and freshwater, have been a staple food in many parts of the world since before written history. Fishers are losing the ability to keep pace with an increasing demand for more food from an ever growing world population.

The numbers of fish and shellfish and their distribution are key factors in determining whether or not commercial fishing will be successful. Basically, the population size of organisms is ever changing in response to natural gains and losses. Reproduction and growth rates are balanced by death and predation rates. Also, long-term changes in nature influence cyclic changes in population sizes. Once an organism becomes targeted as a commercially valuable species, fishing will also tend to reduce the population size. Overfishing can further reduce the numbers until the fish virtually disappear. Fish and shellfish are only abundant in areas of high productivity where nutrients, such as nitrogen and phosphorus, are also abundant. In the presence of sunlight, algae use these nutrients to grow; and the algae are the oceanic plants that other organisms eat. These types of abundant nutrients and algal growth are limited to two areas: shallow waters over the continental shelves, and upwelling areas where nutrient-rich waters from the depths of the ocean return to the surface.

Continental shelves and upwelling areas are being worked with new and more efficient fishing and fish-processing techniques every year, resulting in quicker and larger catches. Thus, the diminishing size of fish populations will very soon become a limiting factor.

One way modern science is trying to provide a consistent harvest from the ocean without harmfully decreasing the numbers of organisms

is through aquaculture. Aquaculture is to the water realm what agriculture is to the land. Shellfish can be successfully started and concentrated in very favorable marine environments, where they are tended and harvested. Several different types of fish can be penned, fed, and protected from predators in large underwater enclosures. As long as the enclosures permit free circulation of water, then the highly concentrated number of fish will be free of disease, and their body wastes will be harmlessly recycled. These same concepts can be applied to freshwater fish like trout and catfish.

Research in the areas of marine and freshwater aquaculture has to include biologic, physical, and chemical aspects of the growth environment. Some fruitful research in these areas has been done, but much more will be needed if we are to provide a continuous, ecologically sound supply of fish and shellfish to satisfy a world's hunger.

Landscapes

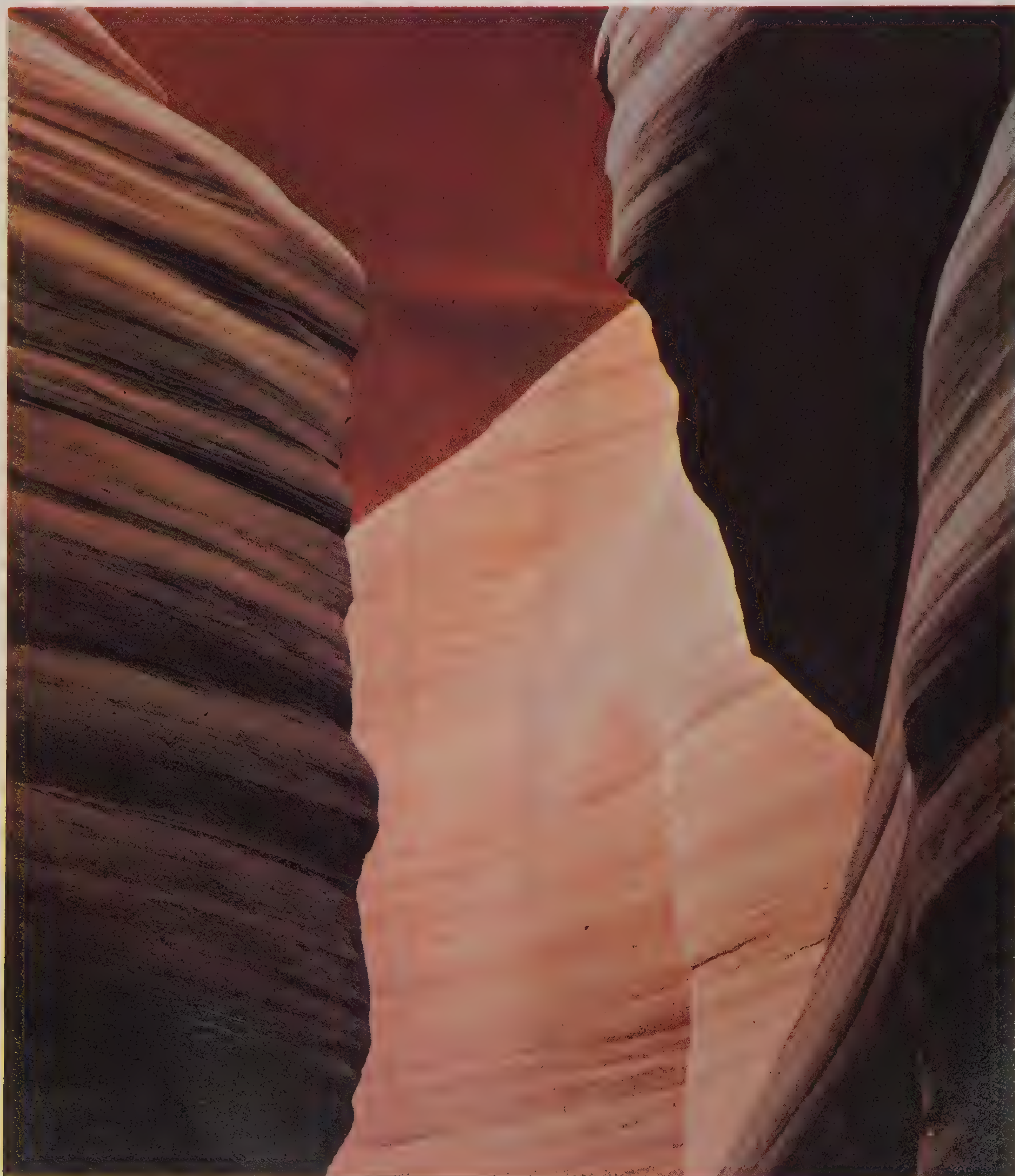
Unit 5

Motion and change are apparent in the earth's atmosphere. Motion and change are apparent in the earth's position relative to the sun, moon, and stars. Motion and change are apparent in the earth's oceans, rivers, streams, and lakes. Not so apparent is the fact that the earth's land masses are also subject to motion and change.

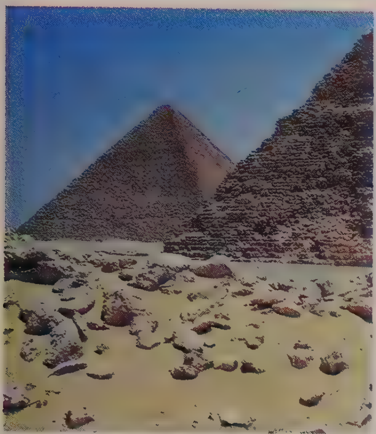
Sometimes, motion and change in the earth's crust are sudden and violent. Earthquakes and volcanoes are examples of such changes. Other times, the changes are taking place over much longer periods of time and are caused by weathering, erosion, and deposition of earth materials.

Any landscape you look at is the result of earth processes acting on earth materials. That landscape will continue to change throughout the earth's future. Such changes are part of the beauty and dynamics of earth science and the ever-changing earth.

Chapter 9



The Earth's Changing Surface



Section 1

Weathering

The earth's face is constantly changing. The part of the earth's surface that is water moves in a variety of ways. Water on the land flows downhill toward the sea. Water in lakes and oceans moves in waves and currents.

The part of the earth's surface that is covered with vegetation grows and dies and decomposes.

The part of the earth's surface that is rock is constantly being broken down into smaller pieces and into different combinations of elements.

Section 2

Erosion

Gravity causes wind, water, and glaciers to move constantly over the surface of the earth, carrying along with them any particles they are able to.

Glaciers carry particles that vary greatly in size. The size of the particles that water can carry depends on the speed and volume of the water. Wind carries only small particles.

Section 3

Deposition

As part of the earth's surface is being broken down, other parts of it are being built up. The particles of the earth's surface that are broken down and carried away become deposited somewhere else. There they can build up to very thick layers and become cemented into rock.

The wearing down and building up of earth surfaces are part of the balance in which earth materials are recycled. The materials may change form and location and composition. But the elements remain the same.

Various landforms cover the earth's surface. In some of them, the effects of earth processes are more evident than in others. What earth process(es) do you think might have shaped the walls of Jada Canyon, Arizona, pictured on the facing page?

Weathering Section 1

Section 1 of Chapter 9 is divided into five parts:

Physical weathering

Chemical weathering

Mixed weathering

Rates of weathering

From rock to soil

Figure 9-1. When people want a structure to last, they build it out of rock. But not even rock lasts forever.

If you leave a bicycle out in the rain, parts of it will probably rust. If you want a wooden building to last long, you keep a coat of paint on it to protect it from the sun and the weather. Roadways crack, split, and wash away. Bridges rust and corrode. Stone buildings, monuments, and statues are worn away. Nothing on the earth's surface escapes the effects of the atmosphere, not even the highest and hardest mountains.

Are even the highest and hardest mountains changed by the earth's atmosphere?

Physical weathering

The weather in the earth's atmosphere acts upon the surface of the earth, causing even the hardest of rocks to change. By means of water, wind, and chemicals, the atmosphere attacks the land and breaks down its rock surface. This breaking down and wearing away of the earth's rocks by the earth's atmosphere is called **weathering.**

One kind of weathering changes only the size of the rock. Large rock masses are broken down into smaller pieces of the same rock material. An example would be pieces of granite at the foot of a granite cliff. This type of weathering is called **physical weathering.** The size of the rock is changed, but the kind of rock is not changed.

What causes physical weathering on the surface of rocks? One cause has to do with changes in temperature. The high temperatures of summer cause the rock material to expand, or get larger. In winter, the low temperatures cause the rock material to contract, or get smaller. Over the years, this expanding and contracting weakens the rock material, causing it to crack and to break off. Because rock is a poor conductor of heat, this expanding and contracting occur mostly on the surface of the rock. It is the surface rock material, therefore, that is most affected by temperature changes.

Another cause is known as frost wedging and hydrofracturing. Water in tiny cracks in rocks freezes from the outside surface toward the inside. Due to this kind of freezing, the pressure from the ice and trapped water increases as the water continues to freeze deeper into the rock. This pressure can, by means of countless tiny fractures, actually split the rock.

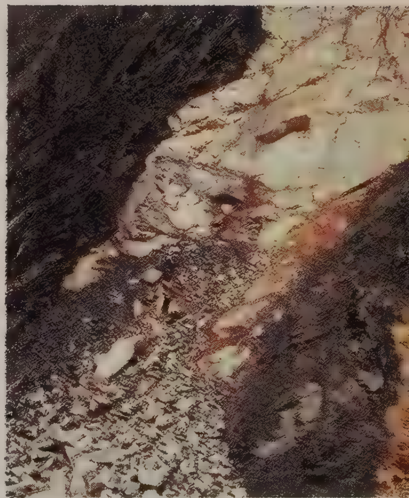


Figure 9-2. Fragments of granite at the base of a granite formation are an example of what type of weathering?

The roots of shrubs and trees also cause physical weathering. Some plants can grow in between the cracks in rocks. As the plant roots grow, they push against the sides of the cracks in the rock surface. The surface of the rock weakens and pieces of rock finally break off. As more and more rock pieces break off, the crack becomes larger. This allows even more room for water to collect or roots to grow. Animal burrows also promote physical weathering by removing some of the underlying support of rocks.

How can even animal burrows promote physical weathering?

Temperature changes and the roots of shrubs and trees can break down a large rock mass into a pile of smaller pieces of the same rock material. The many small pieces are the results of physical weathering.

Check yourself

1. How can temperature changes cause physical weathering?
2. How can the roots of plants cause physical weathering?

Chemical weathering

Physical weathering changes only the size of the rock material. But there is a kind of weathering that changes the material itself. You have most likely seen patches of rust on a steel wool pad, cast-iron frying pan, bicycle, or other object that contains iron. The rusting of iron is actually a form of weathering. In this kind of weathering, a change takes place in the material itself. It is no longer the same material that it was before the weathering took place.

Figure 9-3. Is rusting an example of physical weathering or chemical weathering?

When rust forms, iron combines with oxygen from the air to form iron oxide, a new substance with different properties than either iron or oxygen. Iron, for example, is attracted by a magnet, but the iron oxide in rust is not. This kind of weathering, in which a different substance is formed, is called **chemical weathering.**

Sometimes you can observe orange discoloration in a rock. The rock may have become brittle. Pieces can easily be chipped off. The orange color is probably a sign of iron oxide in the rock. The original rock contained iron or minerals with iron.

A form of chemical weathering known as oxidation has changed the iron to iron oxide.

Sometimes when the outer layer is chipped away, the inner rock appears to be a different color. The outer rock layer has undergone chemical weathering, but the inner layer has not. Different minerals have been formed in the outer layer.

There is some evidence that the freezing of water in rocks creates ideal conditions for chemical weathering. As water freezes, it expands 9%. The resulting pressure can force films of water into micropores and crevasses within the crystal structure of the rock. There the water can weaken the rock chemically.

A form of chemical weathering known as carbonization causes caves to form in rock material. Carbon dioxide from the air dissolves in water to form carbonic acid. This weak acid reacts slowly with some minerals found in rocks. One rock that is affected is limestone. Huge limestone caves can be formed over long periods of time by running water that contains dissolved carbon dioxide. The water flows through underground cracks in the limestone. The carbonic acid continues to dissolve more and more of the limestone along the surface of the cracks until a cave is formed. As years pass, the cave becomes larger and may be many meters high and many kilometers long.

Library research

Prepare a report on sink holes such as those that have occurred in the state of Florida. What causes them? Can anything be done to reduce the amount of damage that is caused by them?

Figure 9-4. Limestone caves form when carbonic acid dissolves the limestone. How does carbonic acid form in nature?

If a small amount of an acid is dropped onto a piece of limestone, gas bubbles can be observed on the limestone surface. A chemical reaction is occurring. The rock releases carbon dioxide gas as the acid reacts with the limestone or calcium carbonate mineral in the limestone rock. Can you imagine what would happen if you continued to add acid to the limestone? In a limestone cave, the chemical reaction is much slower, but it has been going on for thousands of years.

Library research

Working with a small group, prepare a presentation on underground caves. Many beautiful illustrations are available for a classroom display.

Check yourself

1. How does chemical weathering differ from physical weathering?
2. Explain the formation of limestone caves as an example of chemical weathering.

Mixed weathering

In nature, it is hard to separate chemical from physical weathering. Both often occur at the same time.

The longer that weathering takes place, the smaller the rock pieces become. Physical weathering continues when pieces of rock fall onto other pieces of rock and smash them into smaller bits. It continues as the pieces of rock get smaller when rubbed against each other, as during a landslide or while being carried along by a stream.

What kind of weathering takes place when rock fragments strike and rub against each other?

Chemical weathering often takes place at the same time as physical weathering. Freezing water forces films of water into very tiny pores in rock where the water reacts chemically with the rock. Running water or weak acid dissolves some of the minerals in rock fragments that are being physically weathered. The roots of growing plants, in addition to exerting pressure against rock, also have a chemical effect on the rock. As pieces of rock become smaller, more and more of the rock material itself is also being changed.

Have you ever wondered where the sand at a natural beach comes from? In most cases, the sand comes from the weathering of nearby rock layers. The sand at most beaches is made of small grains of the mineral quartz. Because of its hardness,

quartz resists weathering more than any other common mineral. Quartz remains when weathering removes less resistant minerals that were present in the rock. If you examine the rock layers near such a beach very carefully with a magnifying glass, you can observe the grains of quartz.

Figure 9-5. Where in this picture can quartz probably be found?

Check yourself

1. What is the relationship between chemical weathering and physical weathering?
2. What mineral is beach sand often composed of? Why does this occur?

Rates of weathering

Not all weathering of rock takes place at the same rate. The speed at which a rock weathers depends on several things: 1) the type and hardness of the minerals in the rock, 2) the type of rock, 3) the climate, 4) the topography, and 5) the exposure of the rock.

The minerals in a rock affect the rate at which the rock weathers. Rocks made up of minerals that dissolve easily in water weather faster than rocks made of water-resistant minerals. Rocks made up of minerals that react with acids and with substances dissolved in water also weather faster. Limestone, as you have seen, is one example of a rock that weathers quickly when acid is present.

Of the three types of rock, sedimentary rock generally weathers faster than igneous or metamorphic rock. Most sedimentary rocks form from grains that have been cemented together. Sedimentary rock is therefore more porous than igneous or metamorphic rock. Water can permeate the rock more easily. Often the cement is a mineral that water can easily dissolve. That is why sandstone, for example, tends to weather faster than granite.

The climate of an area also affects the rate of weathering. The more precipitation in an area, the faster is the rate of weathering. Rocks weather fastest in a humid climate with a wide range in annual temperatures. In the United States, for example, rocks weather faster along the East Coast than they do in the dry Southwest.

Figure 9-6. In the past one hundred years, the obelisk called Cleopatra's Needle has weathered more than it did in the previous three thousand years.

Around 1500 B.C., the people of ancient Egypt built tall stone monuments called obelisks. Even though 20 m or greater in height, each obelisk was carved from a single piece of rock (usually red granite from a quarry at Aswan). The builders also carved writings on the sides of these granite obelisks.

A little over a hundred years ago, in 1880, one of these obelisks came to New York City as a gift to the American people. Before coming to New York, this obelisk (now called Cleopatra's Needle) had been exposed to the climate of Egypt for over 3000 years. Even so, the writing on its sides had weathered very little. But in the hundred years or so in New York City, the writing has been almost completely weathered away.

One key to explaining what happened to the writing on the sides of Cleopatra's Needle lies in the difference in climate between the two locations. Egypt is warm or hot all year long, and very dry. New York City has cold winters and hot summers and much more precipitation than Egypt. Another key has to do with substances found in the air in New York City which increase the rate at which chemical weathering occurs.

How do substances found in the air in New York City affect the rate of chemical weathering?

Check yourself

1. Why does sedimentary rock weather faster than igneous or metamorphic rock?
2. How can climate affect physical weathering? How can it affect chemical weathering?

From rock to soil

Physical and chemical weathering are important in the formation of soil, the loose material on the surface of the earth that supports plant life. Profiles 1, 2, 3, and 4 in Figure 9-7 show how soil forms when rock is weathered.

Profile 1 shows the solid layer of rock from which soil will form. This layer of rock, which is under every soil, is called **bedrock.** In Profile 1, very little weathering has taken place.

Profile 2 shows the first stages of soil formation. Weathering has caused large fragments of rock to break off from the solid rock. Water can easily penetrate to the bedrock, which is now below the surface.

In Profile 3, zones of different particle sizes have formed. The particles near the surface are the smallest because they have weathered the longest. The particles near the bedrock are larger because weathering has begun there more recently.

Profile 4 shows a fully developed soil profile. Nearest the surface is a layer of **topsoil.** This layer contains **humus,** which is a dark brown or black substance that is formed when dead plants and animals decay. Humus is very rich in materials which plants need for growth. Because of humus, plants grow readily in topsoil.

Humus is an organic material. All organic materials contain the element carbon, an element found in all living things. Humus contains carbon because humus is formed from the remains of plants and animals that were once alive.

Chemical weathering of soil changes its mineral content. Water filtering down through the topsoil removes some of the minerals. This process is called **leaching.** In the zone of leaching (the topsoil layer), only the minerals that are most resistant to weathering remain unchanged.

Library research

Present-day conditions are speeding up the weathering of ancient and priceless stone statues and buildings in Greece and Italy. Find out what is being done to preserve these statues and buildings from weathering.

Activity Comparing Samples in a Soil Profile

Materials

2 or 3 soil samples from different levels of a road cut
rock sample from lowest part of road cut
several sheets of blank white paper
toothpick (or teasing needle)
magnifying glass

Purpose

To look at relationships between soils and rocks.

What to Do

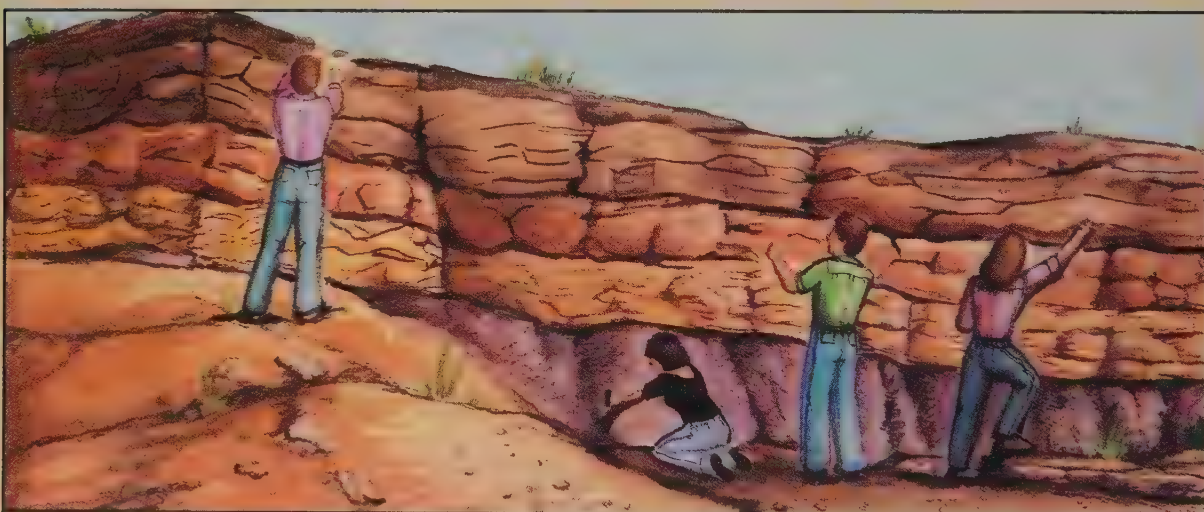
1. Pour a small quantity of soil from the sample from the highest level of the road cut onto a piece of paper.
2. Using the teasing needle and a magnifying glass, separate the sample into piles of similar materials.
3. Do the same for each of the other soil samples.

Questions

1. When examining the first sample, how did you decide which fragments were the same material? (Size, color, shape, and so forth?)
2. How do the different piles of materials compare—from the level nearest the surface to the deepest level?

Conclusion

How does the soil compare with the rock? Would you say that the soil formed from the rock or from other sources? Explain.



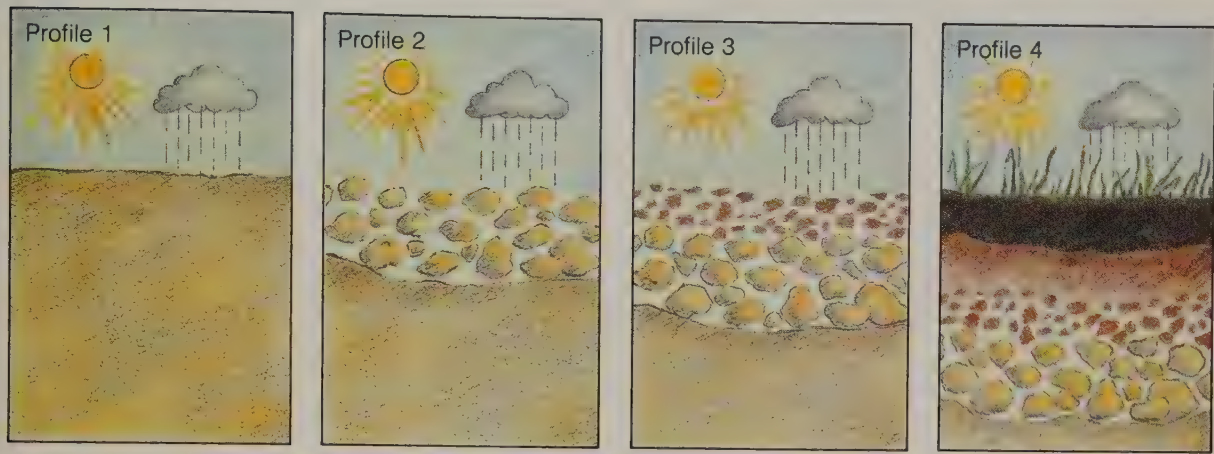


Figure 9-7. What is the name of the layer of rock that is under every soil and that appears in all four of these profiles?

As shown in Profile 4, a layer of **subsoil** is found under the topsoil in a fully developed profile. Clay and other substances that have filtered down from the zone of leaching accumulate in this layer of the soil. The soil in this zone of accumulation contains few of the elements needed by plants for growth. If the topsoil is removed from an area and the subsoil is exposed, plants will not grow readily in the exposed subsoil.

Because climate affects the rate of weathering, it also affects the formation of soil profiles. In areas where the climate is humid and there is much precipitation, a soil profile several meters thick can develop in a period of a few thousand years. In desert regions, however, where there is very little water, weathering takes place much more slowly. Soil found in a desert is usually sandy and the particles are much larger than the tiny soil particles of a fully developed soil profile.

Does climate affect the formation of soil profiles?

Check yourself

1. In a soil profile, where are the smallest particles found? Why?
2. How does climate affect the formation of soils?

Activity Comparing Rates of Chemical Weathering

Materials

chips of carbonate rock fragments (marble, limestone, dolomite), sandstone, granite, and any other rock you'd like to try

250-mL beakers or jars (1 for each sample)

laboratory balance

10% dilute hydrochloric acid

wire screen

graduated cylinder

water

Purpose

To compare weathering rates in different rocks.

What to Do

1. Pour enough fragments of each sample into a beaker to fill it ¼ full.
2. Rinse the fragments in each beaker with water to remove any loose, tiny grains. Turn on the faucet and let water run slowly into the beaker. When full, place the wire screen on top of the beaker to prevent any fragments from falling out when you pour off the water. Repeat several times for each sample.
3. Next, use the balance to find the combined mass of the beaker and rock fragments for each sample. Record the data on a table like the one shown.
4. Using a graduated cylinder, measure out 100 mL of dilute hydrochloric acid and pour it over the rock fragments in the first beaker. Add an equal amount to each of the other beakers, too. Put the beakers aside until the next day.

   SAFETY NOTE: *Do not handle concentrated hydrochloric acid. Make sure the acid you work with is 10 percent dilute, which your teacher will provide. Do not get any of this dilute acid on your body. If you do, wash with plenty of clear water.*
5. On the second day, pour off the acid from each beaker, using the wire screen to keep the fragments from falling out. Pour the acid down the drain.
6. Rinse and drain the fragments in each beaker several times with fresh water from the faucet, as you did the previous day.
7. Carefully measure and record the combined mass of each beaker and fragments.
8. As before, add 100 mL of dilute acid to each sample and set aside until the next day. Then follow steps 4–7.
9. At the end of the activity, rinse all fragments thoroughly to remove any dilute acid.

Questions

1. Which rock sample weathered more? How does your data explain your answer?
2. What change, if any, was there in the amount of weathering from one day to the next? What might explain this?

Conclusion

In addition to rock type, what else might influence the rate of chemical weathering?

Rock Sample	Combined Mass Day 1	Combined Mass Day 2	Combined Mass Day 3	Combined Mass Day 4	Combined Mass Day 5
A					
B					
C					
D					

Careers Geographer / Civil Engineering Technician

Geographer Geography has often been described as the beginning of the sciences. The word *geography* means "earth description." Many years ago, students studied geography. Now it is called earth science.

A geographer conducts research on the nature and use of the many areas of the earth, as well as on the distribution of people and resources. There are many special areas in which a geographer may work. Some of these are soils, climates, mineral resources, water resources, and their relation to people.

If you were to enter this field, it would be necessary to complete college. You should have a well-rounded background in the sciences but not necessarily a great deal of science.

You could expect to find job vacancies in colleges and universities. The federal government employs geographers in intelligence agencies. Local and state governments, market research firms, and travel groups also employ geographers.

A geographer's tasks may require working out-of-doors, in offices, or in laboratories. Travel is frequently necessary.

Civil Engineering Technician Engineers and engineering technicians use scientific and mathematical discoveries to solve practical problems in many different areas of modern life. Civil engineering is the branch that deals with the design and construction of highways, bridges, water supply systems, and similar structures.

Functions that may be performed by civil engineering technicians include the preparation of cost estimates, materials specifications, and construction schedules. They may also assist with surveying, drafting, and designing.

If you enjoy technical work, a career in civil engineering may interest you. To prepare, take science and math courses in high school. Then you might attend a technical institute, community college, or vocational school. Some engineering technicians have learned their skills through on-the-job training, but, in general, those with some education after high school have greater job opportunities.

Civil engineers and technicians are employed primarily by government agencies and by the construction industry.

The plan and profile this civil engineering technician is preparing will be used to improve drainage and reduce erosion.

Section 1 Review Chapter 9

Check Your Vocabulary

bedrock	subsoil
chemical weathering	topsoil
humus	weathering
leaching	
physical weathering	

Match each term above with the numbered phrase that best describes it.

1. The breaking down and wearing away of the earth's rocks by the earth's atmosphere
2. A kind of weathering in which a material is changed only in size, becoming smaller as a result of the weathering action
3. A kind of weathering in which different substances are formed
4. A layer of solid rock that is under every soil
5. The layer of soil that contains humus; found in a fully developed soil profile
6. An organic substance rich in materials that plants need for growth
7. The removal of minerals in the topsoil layer by water that is filtering down through the soil
8. The layer of soil that is found under the topsoil of a fully developed soil profile; contains few elements needed by plants for growth

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Expansion and contraction are caused by ?.
   a) rusting
   b) chemical weathering
   c) changes in temperature
   d) rain
2. Oxidation and carbonization are examples of ?.
   a) physical weathering
   b) leaching
   c) chemical weathering
   d) subsoils
3. As water ?, it expands.
   a) condenses c) falls
   b) freezes d) infiltrates
4. In the formation of limestone caves, ? and carbon dioxide in the air combine to form weak carbonic acid.
   a) red granite
   b) calcium carbonate
   c) clay
   d) water
5. Because of its ?, quartz resists weathering more than any other common mineral.
   a) permeability c) porosity
   b) hardness d) cement

Check Your Understanding

1. How does water affect physical weathering? How does it affect chemical weathering?
2. Why do caves generally form in areas where there is limestone?
3. Which will retain fine details longer—a sandstone statue or a granite statue? Why?
4. In which type of climate would a stone statue probably undergo the least weathering? Why?
5. As time passes, what happens to the size of the particles in a soil profile? What happens to the layers (number and size) in a soil profile? Why?

Erosion Section 2

Section 2 of Chapter 9 is divided into five parts:

Erosion by running water

The formation of a river valley

Erosion by glaciers

Erosion by more than one agent

Controlling erosion

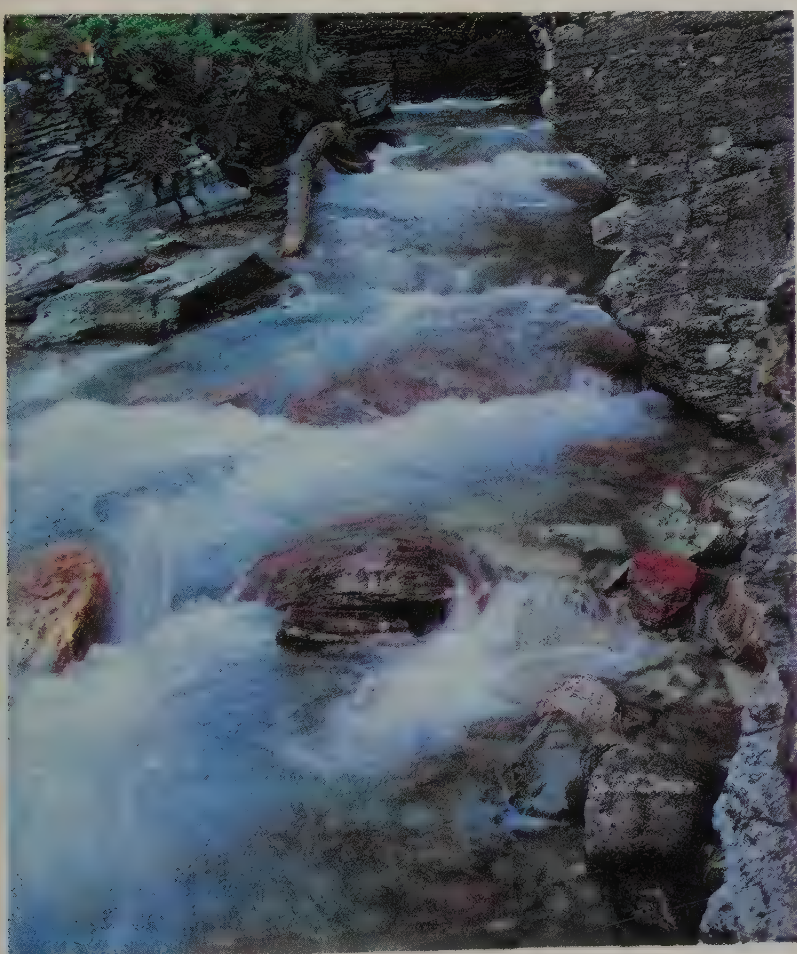


Figure 9-8. Rocks that fall into a stream can be changed by the running water. How can they be changed in terms of their size, shape, composition, and location?

Rock fragments are found at the base of a rock cliff. A closer look reveals that the fragments are composed of the same minerals as the rock cliff. Chemical and physical weathering have caused the fragments to break off the cliff. When you look at the cliff, you may notice that more of the cliff has been weathered away than can be explained by the fragments at its base.

What happened to the other rock fragments? They were most likely carried away by a natural agent such as running water. If there is a stream in the area, you will probably find rock fragments in the stream bed that contain the same minerals as the rock cliff.

The transporting of the products of weathering is called **erosion** (i-RŌ′-zhin). Four common agents of erosion are running water, glaciers, gravity, and wind.

Erosion by running water

In almost all areas, running water is the dominant agent of erosion. When it rains, loose material is picked up and carried along by the rainwater running off the surface. (Even the splash of raindrops can loosen surface material.) As the runoff enters streams, it carries some of the loose weathered material along with it as mud, silt, sand, and pebbles. How far that material is carried depends on both the size of the particles of material and the force of the moving water.

You may have seen rocks or pebbles at the bottom of a stream. Chances are that they were carried to the stream by runoff water or that they fell into the stream because of gravity. The rocks and pebbles probably entered the stream closer to the stream's source and are being slowly carried downstream by the water. Furthermore, rocks with rounder edges have probably been carried farther by the stream.

The rocks and pebbles may not appear to be moving. But little by little, because of gravity and the force of the running water, the fragments and particles move downstream. Large fragments of rock may move only very short distances. Smaller fragments, like pebbles and gravel, travel much greater distances. Very small particles keep moving until the stream or river empties into a lake, reservoir, or sea.

Figure 9-9. The mud in this river is being carried in suspension. What will happen to the particles of mud when they reach a part of the river where there is little or no water movement?

All the material transported by a river or stream is called the **stream load.** The smallest particles, which are too small to be seen with the naked eye, are being carried in solution. That is, they are dissolved in the water. In most rivers and streams, the water looks clear. Suppose you collected a sample of clear water and let the water evaporate. You would probably notice some very fine material that remained on the sides and bottom of the container. This material, which had been dissolved in the water, was being carried unseen in solution.

How much of the material transported by a stream makes up the stream load?

Other small particles are carried in suspension. That is, they are suspended in the water by the movement of the water. When they reach a point where the water stops moving, they settle to the bottom. Muddy water contains small particles of clay that have been stirred by the moving water and are suspended in the water. Suppose you collected a jar of this water and left it to stand. Soon, the water would start to clear as particles in suspension settled to the bottom of the container.

The process of weathering continues while erosion is taking place. The particles carried by a stream strike each other and strike particles on the stream bed. The farther downstream they are carried, the smaller, rounder, and smoother they become. Through physical weathering, large fragments eventually break into bits small enough to be carried along in suspen-

How do particles of rock change as they are carried farther downstream?

Our Science Heritage

Travel and World Geography

Two thousand years ago, the Greek geographer Strabo observed and described the countries around the Mediterranean Sea.

Today, if people want to know what it's like in China, they can start to find out at their nearest library. There they will find many resources, including atlases, descriptive nonfiction works, and the various kinds of publications for which organizations like Time-Life, Incorporated, and the National Geographic Society are famous.

Such was not always the case. The total picture of the earth, which we can now take for granted, is the result of centuries of travels, explorations, observations, and the keeping of accurate records and journals.

The ancient Greeks were the first people to want to know why different peoples lived differently. And they kept records of what they observed. Strabo, a Greek geographer and historian who lived from 63 B.C. to 24 A.D., traveled throughout the lands surrounding the Mediterranean Sea. His 17-volume geography describes all parts of the world known to the ancient Greeks and is still available and recognized as the best source of geographical information on the Mediterranean countries as they were 2000 years ago.

As you become more familiar with world geography and world history, you will come to appreciate the part various travelers, writers, naturalists, and geographers have played in extending our knowledge of the world out to its present boundaries.

sion. Through chemical weathering, some of the minerals in the fragments dissolve and are carried along in solution.

The amount of material carried by a stream (that is, the stream load) depends on the speed of the water and the volume of the water in the stream. A fast-moving stream can carry larger particles than a slower-moving stream. The amount of material transported also depends on the amount of water that is moving along. A slow-moving, large river can carry far more material than a fast-moving mountain stream.

Check yourself

1. How do particles in solution differ from particles that are in suspension?
2. What two factors affect stream load?

The formation of a river valley

Almost everywhere on the earth you can find landscapes carved by running water. One of the most common examples is a river valley that is formed between two mountains. The three states shown in Figure 9-10 are typical of what happens.

At Stage 1, a fast-moving stream or river tumbles down the steep slopes between the sharp peaks of the two mountains. It begins to carve a valley between the peaks. Rainwater flows down the mountainsides, carrying small particles weathered from the rocky mountainsides. Eroded pieces, fragments, and particles of rock from the mountain peaks become the stream load and are transported down the slopes by water.

Library research

Find out the importance of the investigations of Nicolas Desmarest regarding the formation of river valleys.

As time passes, the valley becomes wider and wider. Running water continually removes material from the sides of the mountains. The mountain peaks become lower and rounder because of the weathering and eroding action of the water. As the river erodes the mountain, it cuts its channel to a lower elevation. More streams form, capturing and draining water from a larger area into the river valley.

During Stage 2, the steepness of the river channel decreases, and the river valley becomes wider as the river curves and flood plains start to develop. A **flood plain** is a fairly flat area next to a river and nearly at river level. A flood plain is created by sideways erosion on the outside and deposition on the inside of a river's curve.

What is a flood plain?

Even though the river is getting wider, it cannot contain the increased flow volumes that occur after heavy precipitation and runoff. At such times, the river overflows its banks and leaves deposits of sediments. The coarser sediments fall out of the flood waters as they first move out of the riverbed and over the bank. These deposits form a natural **levee** (LEV′-ee) on both sides of the river.

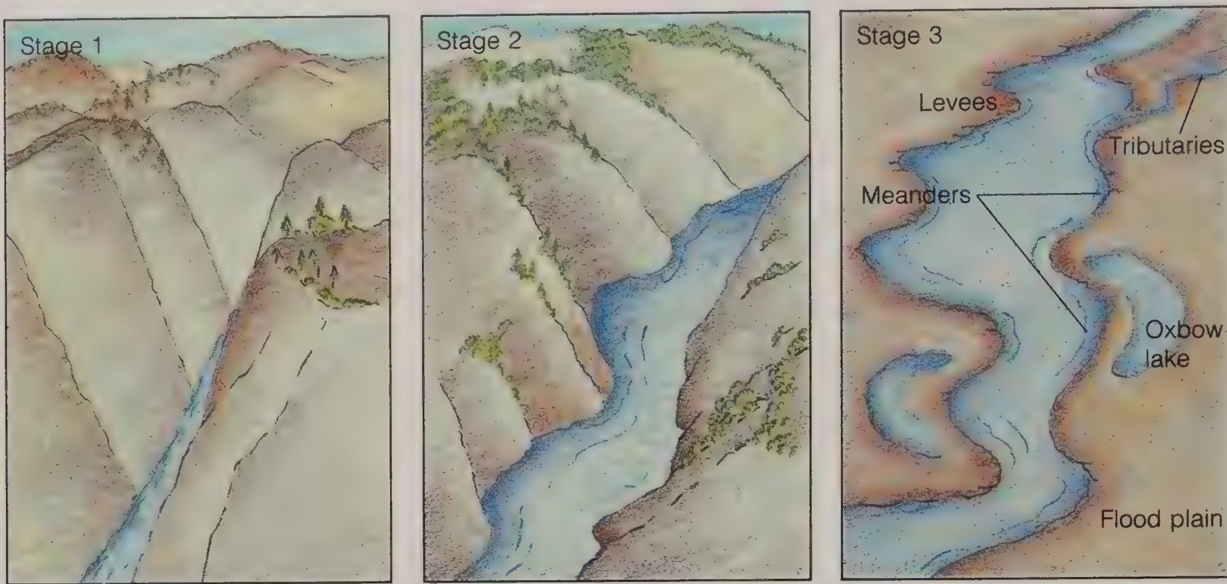


Figure 9-10. At which of the three stages in the formation of a river valley is the water moving the slowest?

As the steepness of the river channel decreases, the river's course forms bends called **meanders** (mee-AN′-derz). Although the river is still eroding downward, the sideways erosion is increasing. The surrounding slopes are becoming less steep and the valley is being widened. River water velocity in non-desert climates stays the same or slightly decreases from Stage 1 to Stage 3. The energy in the moving water from Stages 1 to 2 to 3 is gradually shifted from downward erosion to sideways erosion. Every river has a limit to its downward erosion. This limit is the level of a lake or ocean that the river empties into, and it is called **base level.**

By Stage 3, the valley has become very wide and approaches base level. The river has such large meanders that they sometimes intersect each other, and the river flow then bypasses the cut-off meander. Sediment slowly fills in both ends of the cut-off meander, forming what is known as an **oxbow lake.** The wide, Stage 3 flood plain makes excellent farmland because the deposits from floods continually add nutrients to the soil.

Can the climate of an area affect the type of river valley that forms?

The climate of an area can affect the type of river valley that forms. As examples, consider the Susquehanna Valley and the Grand Canyon. Both landscape systems have been forming for millions of years. Both have been produced by running water. But both are very different in appearance.

The Susquehanna Valley is located in an area with a high annual rate of precipitation. It has a very wide flood plain. The

Figure 9-11. A portion of a meandering river can become separated from the river by sediment. What is the resulting blocked-off body of water called?

mountains that form this valley have gently sloping sides. Precipitation can increase rates of erosion and weathering, which cause a valley to widen. Humid climates with high annual amounts of precipitation often produce wide river valleys with gently sloping mountainsides.

The Grand Canyon, on the other hand, is narrow with steep walls. Its flood plain is very small. The Grand Canyon is located in a very arid climate, where there is little rainfall. Arid climates produce deep and narrow river valleys with steep canyon walls.

Check yourself

1. How does the steepness of the riverbed and the speed of the water change from Stage 1 to Stage 2 to Stage 3 in the formation of a river valley?
2. Why wouldn't a flood plain develop at Stage 1?

Erosion by glaciers

The influence of glaciers, which are moving masses of ice, is confined to the cold regions where they are found. In these regions, snow does not completely melt in summer and thus builds up from season to season. In time, the mass of the snow on the top changes the snow on the bottom to ice. Under great pressure from its own weight, the ice begins to flow. A glacier has formed.

Library research

Find out more about John Wesley Powell and his contributions to our knowledge of the geology and landscape features of the American Southwest.

How much does a glacier move in a day?

The rate of movement of a glacier is too slow to be seen directly. Scientists, however, have measured the rates of movement of glaciers and found them to move a few centimeters or more each day.

A glacier may flow down a mountainside. This kind of glacier is called a **valley glacier** (or sometimes an alpine glacier or a mountain glacier). Valley glaciers, which follow old river channels, flow down between walls of rock.

A glacier may flow outward from its thick center over wide regions of a landscape. This kind of glacier is called a **continental glacier** and is an ice sheet that covers much of a continent. The ice sheet that covers Antarctica is a continental glacier.

Thousands of years ago, huge ice sheets covered the northern part of North America. As these glaciers moved down from the north, they carried with them loose material frozen in the ice. When the ice melted, the loose material was left behind. In some cases, the material included boulders 1 m or more in diameter. (These large water-worn and ice-borne boulders are known as **erratics** (i-RAT′-iks).

How can scientists infer that a boulder was carried by a glacier? The scientists can study the boulder to see what kind of rock it is and what minerals it contains. They can then look for layers of rock that match that of the boulder. In many cases, the matching rock layers are many kilometers away. The scientists then study the slope between the boulder and the matching rock layers to see if a gravity-caused rockslide could explain the movement of the boulder. If gravity is unlikely, then glaciers are the only other agent of erosion capable of moving a boulder such a great distance.

Figure 9-12. In a Stage 1 stream (on the left), the valley bottom is completely filled with flowing water. A flood plain and oxbow lake (on the right) are characteristic of Stage 2 to Stage 3 development of a river valley.

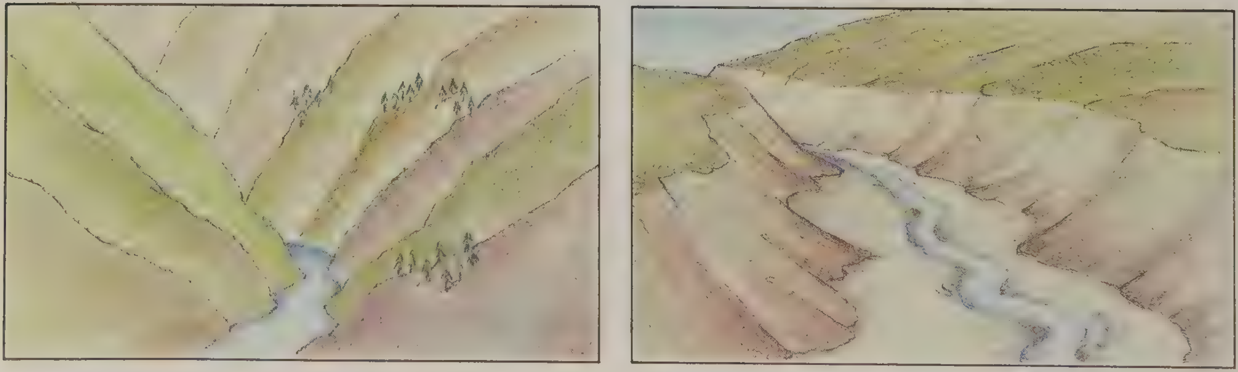


Figure 9-13. Some glaciers flow down a mountainside. How does the shape of this glacier-carved valley compare with the valleys shown in Figure 9-12?

The erosion produced by a glacier is different from the erosion produced by running water. Running water can carry only small particles. Glaciers can carry particles of all sizes—from tiny grains to large boulders. Also, in the case of a valley glacier, the glacier extends up the sides of the valley and erodes the valley walls at the same time it is eroding the base, changing a V-shaped valley to a U-shaped valley. A river of running water, on the other hand, flows along the floor of the valley.

Check yourself

1. How does a valley glacier differ from a continental glacier?
2. How does a valley formed by a river differ from a valley shaped by a glacier?

Erosion by more than one agent

What two agents of erosion commonly shape a desert landscape?

Often a landscape has been shaped by more than one agent of erosion. The landscape in a desert area, for example, is often the work of both running water and the wind. The sand dunes in a desert show the effect of the wind as an agent of erosion. During a windstorm, particles of sand may be carried many meters from their original location. But one period of rainfall

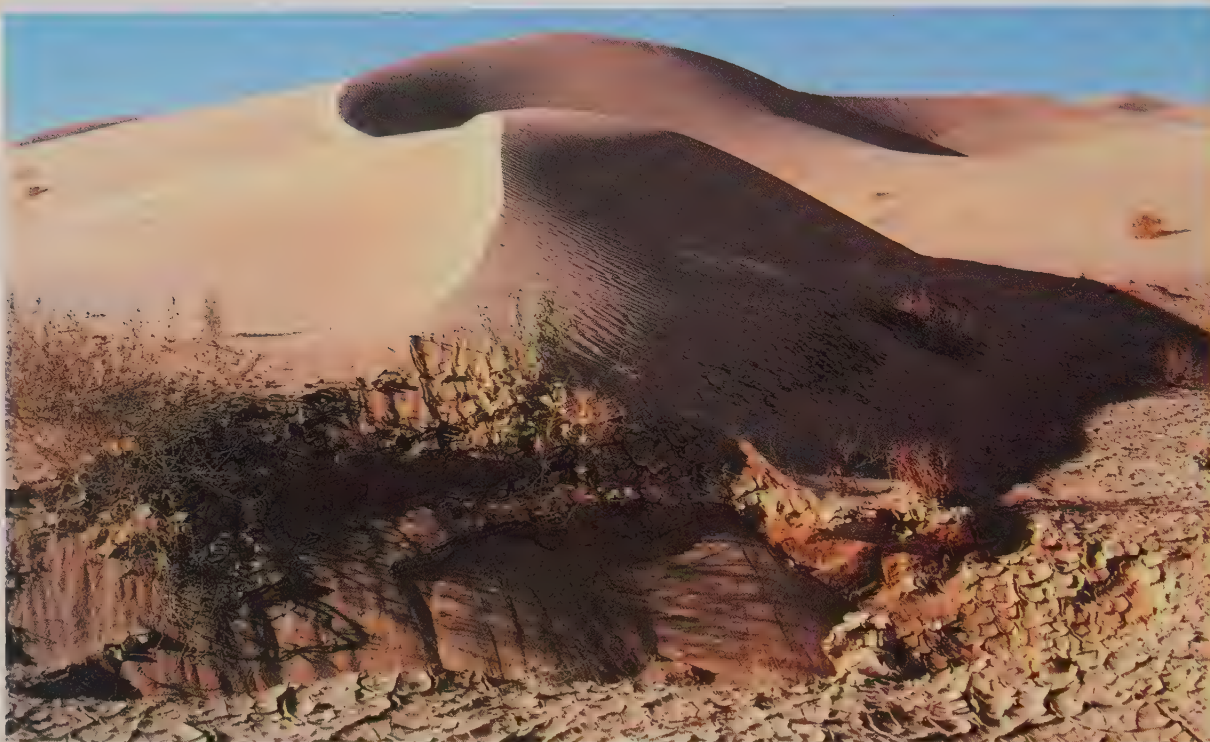


Figure 9-14. Both wind and running water have eroded this landscape. What effect does the agent of erosion have on the size of the particles that are eroded?

in a desert can produce more erosion than several months of wind action. (Also keep in mind that physical weathering and erosion occur together. As particles are eroded, they also become smaller by the physical weathering process of **abrasion** (uh-BRAY′-zhin), in which particles rub and scrape and hit against each other.

Evidence of erosion may suggest which agents were active. It may not be possible, however, to determine which of the agents had the greater effect. In a landslide, it may appear that gravity is the only agent. But the landslide could have been started by rainwater running off the mountainside. In that case, both running water and gravity were the agents of erosion.

Where glaciers are active, the erosional system usually involves both glacial action and running water. The glacier carries the material down the side of the mountain. At the base of the glacier, running water from the melting ice carries some of the material farther along.

Gravity as an agent of erosion is most evident in landslides, rockslides, or snowslides. In a rockslide, weathering weakens the rock surface along a cliff. Fragments of rock break off. Gravity causes the fragments to fall to the base of the cliff.

Gravity is also the underlying force behind all erosion. It is gravity that causes water to run downhill. It is gravity that causes glaciers to flow. And it is gravity that produces winds by pulling heavy colder air down beneath lighter warmer air.

Library research

Prepare a report on erosion by wind. Using examples, show how it affects the landscape. What, if anything, can be done to prevent it?

Check yourself

1. Using glaciers as an example, show how an erosional system usually involves more than one agent of erosion.
2. How is gravity also involved in erosion caused by running water, by glaciers, and by wind?

Controlling erosion

The activities of people can have a marked effect on the erosion of weathered material from the earth's surface. For example, the trees, shrubs, and grasses of undeveloped areas prevent soil erosion. When the land is stripped of this natural vegetation, there is nothing to prevent wind and water from eroding valuable topsoil.

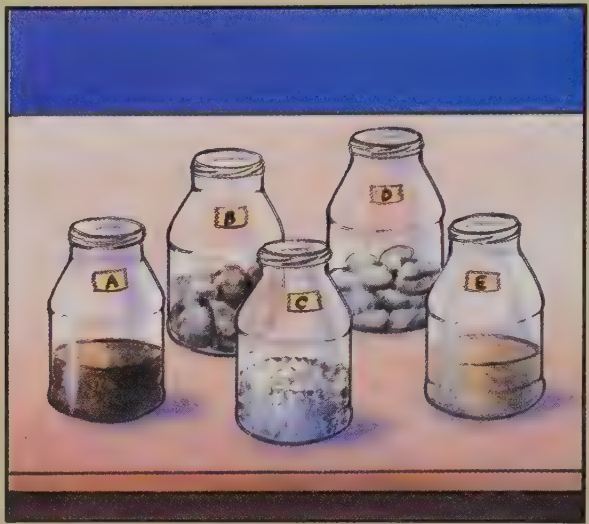
The roots of natural vegetation hold the soil in place. The stems of grasses and other plants act to slow down the flow of runoff. The leaves break the force of falling raindrops. Slower runoff can mean that more water soaks into the ground. And less runoff means less erosion.

Farmers play an important role in maintaining the soil. The best farming methods are those that help to preserve topsoil. If farmers decide not to plant crops on a field, they will let wild vegetation grow. Lumber companies also play an important role when they replant forest areas after cutting down trees for lumber. In replanting, people act to preserve valuable soil and watersheds.

How does replanting affect valuable soil and watersheds?

People also affect erosion when they build dams in rivers. Dams, which provide sources for inexpensive electrical power,

Activity Analyzing Products of Erosion



Materials

- 2 or more samples of products of erosion by running water, in containers labeled A, B, and so forth
- magnifying glass
- ruler

Purpose

To learn what happens to products of erosion in a running-water system.

What to Do

The fragments in each of the containers have been transported from their original locations by running water. Compare the shapes of the fragments and their general appearance.

Questions

1. Which fragments do you think have been transported the greatest distance? the shortest distance? Explain.
2. What do you think would have happened to each type of fragment if it had been transported even farther?

Conclusion

What general conclusions can you draw about rock fragments that are transported by running water?

create lakes where rivers once flowed. The flow of water in the river below a dam can be controlled. Seasonal flooding can be prevented by dams that trap and store much of the sudden increases in water coming from the watershed areas.

There are many places in the world where canals have been dug to provide artificial waterways and irrigation channels. Diverting the water in a river reduces the amount of water flowing in the river. This in turn reduces the amount of erosion that occurs farther down the river.

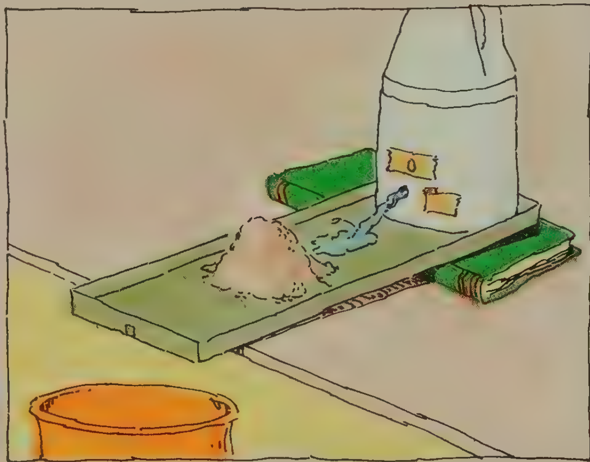
The erosion that takes place along coastlines is much harder for people to control. Over a long period of time, ocean waves erode the coastline. People who have built homes near the coast try to prevent this from happening. In most cases, such attempts have not been successful. Houses built back from the coast have actually fallen into the sea because of erosion by ocean waves.

Library research

Do a report on the channelization of a river (for example, the Missouri River) to control flooding and to stabilize its banks.

Figure 9-15. How does natural vegetation help to prevent erosion?

Activity Changing the Rate of Erosion



Materials

plastic or metal trough
large plastic container with two holes, one above the other, near the bottom
bucket
measuring cup or beaker
fine sand
water
marking pencil
protractor
books or blocks or wood to use as props
1 sheet of plastic
masking tape

Purpose

To study factors that affect rate of soil erosion.

What to Do

1. Using the books, the sheet of plastic, and the trough, set up the trough as shown in the picture. The plastic should cover the books so that they won't get wet. Start with a slope of 10° on the trough.
2. With the marking pencil, mark the side of the measuring cup about 2/3 of the distance from the bottom.
3. Fill the cup to the mark with sand, and empty this sand into a pile about midway down the trough.
4. With the marking pencil, mark the large plastic container about 2/3 of the way from the bottom.
5. Put masking tape over each hole near the bottom of the container. Make sure both holes are completely and tightly covered.
6. Fill the container to the 2/3 mark with water.
7. Put the bucket at the bottom of the trough. Position it so that it will catch any water and sand that comes down the trough.
8. The student who is holding the container should remove the bottom strip of tape and let the water run down the trough. (One or two trial runs may be necessary.)
9. When all of the water has left the container, note how much (if any) of the sand is left in the trough. Record the results.
10. Increase the stream slope 5° or 10°. Repeat the procedure and record your results.
11. With the marking pencil, make a second mark on the container half way between the top mark and the bottom of the container.
12. After making sure that both holes are securely covered with tape, fill the container to the lower mark.
13. Using the smaller slope, repeat the procedure with water flowing through only the bottom hole of the container.
14. Now use a single strip of tape to cover both holes. Fill the container to the lower mark. Remove the tape so both holes are open.

Questions

1. What happened to the rate at which the sand was eroded when the stream slope was increased? Explain.
2. What happened to the rate at which the sand was eroded when the stream volume was increased? Explain.

Conclusion

What factors have you studied that can change the rate of soil erosion? What other factors might change the rate of erosion?

Figure 9-16 How can a shopping mall affect the runoff pattern of an area?

Wherever people are, the landscape changes. To make roadways, hills are leveled and stripped of vegetation. Mountains are tunneled through. Swamps are filled. Wide paths are cleared through forests. To make room for homes and shopping centers, schools and factories, huge tracts of land are cleared.

Think of how a shopping mall can change the runoff pattern of an area. The impermeable surface of the rooftops and paved parking lots permits no rainfall to soak into the ground. All of this water can collect on the surface as runoff and be channeled into a potentially erosive stream. The large areas of impermeable surface can act as funnels, causing a rapid build-up of water and increasing the likelihood of a flash flood.

How can large areas of impermeable surface increase the likelihood of a flash flood?

Urban development greatly affects the landscape. It also affects how the agents of erosion will change that landscape in the future. Urban developers must therefore effectively plan for the discharge of water from paved and developed areas.

Check yourself

1. What are two ways in which people can help prevent erosion?
2. What are two ways in which people can increase the likelihood of erosion?

Section 2 Review Chapter 9

Check Your Vocabulary

abrasion
base level
continental glacier
erosion
erratics
flood plain
levee
meanders
oxbow lake
stream load
valley glacier

Match each term above with the numbered phrase that best describes it.

1. The transporting of the products of weathering
2. All the material transported by a stream
3. The level area between the banks of a river and the foot of the mountains
4. Curves and bends in a stream or river
5. A lake that forms when sediment fills in both ends of a cut-off meander
6. A natural embankment formed on both sides of a river
7. A glacier that flows down a mountainside
8. An ice sheet that flows outward from its center over wide regions of a landscape
9. Larger water-worn boulders that have been deposited by a glacier
10. The physical weathering process in which particles hit against each other
11. The level of a lake or ocean that a river empties into

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. In almost all areas, _?_ is the dominant agent of erosion.
   a) glaciers
   b) wind
   c) running water
   d) gravity
2. Through _?_, some of the minerals in rock fragments dissolve in the water and are carried along in solution.
   a) abrasion
   b) chemical weathering
   c) evaporation
   d) physical weathering
3. As the steepness of a river decreases, the speed of the water _?_.
   a) decreases
   b) increases slightly
   c) remains the same
   d) increases greatly
4. The soil in a flood plain is _?_.
   a) full of erratics
   b) rich in nutrients
   c) not fertile
   d) impermeable
5. _?_ can carry particles of all sizes.
   a) Wind
   b) Running water
   c) Glaciers
   d) Runoff

Check Your Understanding

1. What are four common agents of erosion?
2. What effect does gravity have on erosion?
3. What effect does the steepness of a riverbed have on erosion?
4. How do particles that are carried in suspension differ from particles that are carried in solution?
5. Using examples, explain how in most erosional systems there are two or more agents active.

Deposition Section 3

Section 3 of Chapter 9 is divided into four parts:

Deposition by running water

Stream erosion and deposition

Deposition by wind

Deposition by glaciers

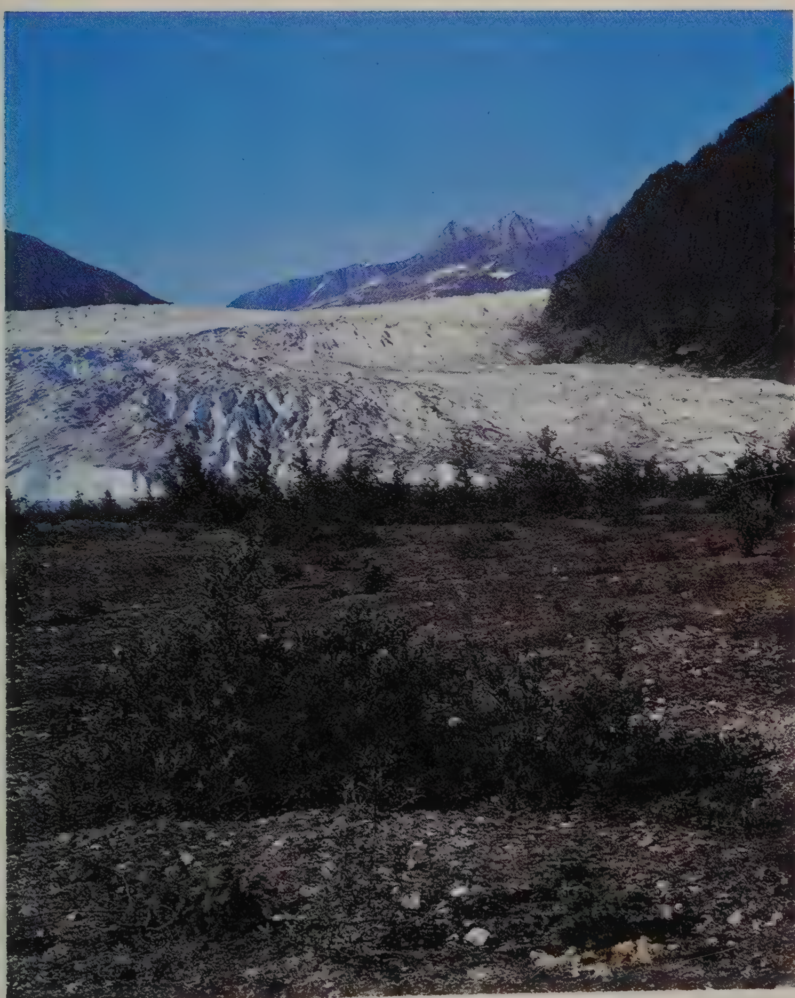


Figure 9-17. This photograph of Mendenhall Glacier (near Juneau, Alaska) shows ground deposits left fifty years ago by the receding valley glacier. What size particles would you expect to find in the deposit left by a receding glacier?

What kinds of evidence in a deposit of earth materials provide clues to the agents of erosion that were active in that area?

Suppose you find a deposit of earth materials many meters thick. The bottom layers contain a wide range of particle sizes. The particles are angular and of different shapes. The upper layers contain particles that are the same size and that are rounded, with smooth surfaces. This evidence provides clues to what happened in that area.

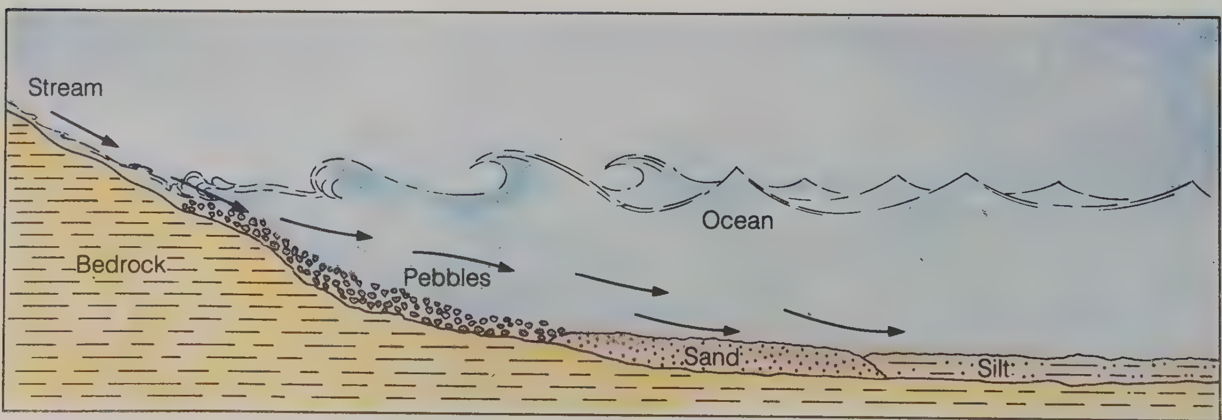
The deposits left by each agent of erosion differ greatly. In the example just mentioned, the evidence indicates both glacial deposits (the lower layers) and deposits eroded by running water (the upper layers). As you might have inferred, **deposition** means the process whereby particles and fragments of earth materials are deposited or laid down by an agent of erosion.

Deposition by running water

Deposits formed from running water contain layers of different particle sizes. Also, the particles deposited from running water are rounded rather than angular. As the particles are carried along by the water, they become round and smooth from striking each other.

Rivers and streams carry particles of weathered earth materials like soil and rock downstream. The size of the particles a stream can carry depends on the volume and speed of the water. When a river reaches the sea, the water slows down. As the flow of the water slows down, the particles begin to settle to the bottom. In a process called **sorting,** the largest and densest

Figure 9-18. This diagram shows a profile of the deposits of material near the mouth of a river. Why are the smaller particles found farther out?



particles settle out first. As the flow becomes slower and slower, increasingly smaller particles settle out until all material has been deposited except the material in solution.

As deposits build up near the mouth of a river, the slope of the riverbed decreases. This further slows down the speed of the water. Smaller and smaller particles settle out in layers as the speed of the flow decreases. That is why a cross section of the deposits near the mouth of a river will show the largest particles near the bottom of the deposit. The particles become smaller and smaller toward the top of the deposit.

Along the coasts of continents, layers of deposits build up wherever rivers flow into the sea. Deposits from large rivers can cover many square kilometers and can be hundreds and even thousands of meters thick.

As a river enters the sea, the particles carried by the river are deposited in the shape of a fan. Because of its shape, a deposit near the mouth of a river is called a delta (from Δ, which is the capital form of *delta,* the third letter of the Greek alphabet).

Delta regions contain rich soils that have formed from materials deposited from the water. Soils formed from eroded materials are called **transported soils.** (Other soils, which remain near the bedrock from which they have weathered, are called **residual soils.**)

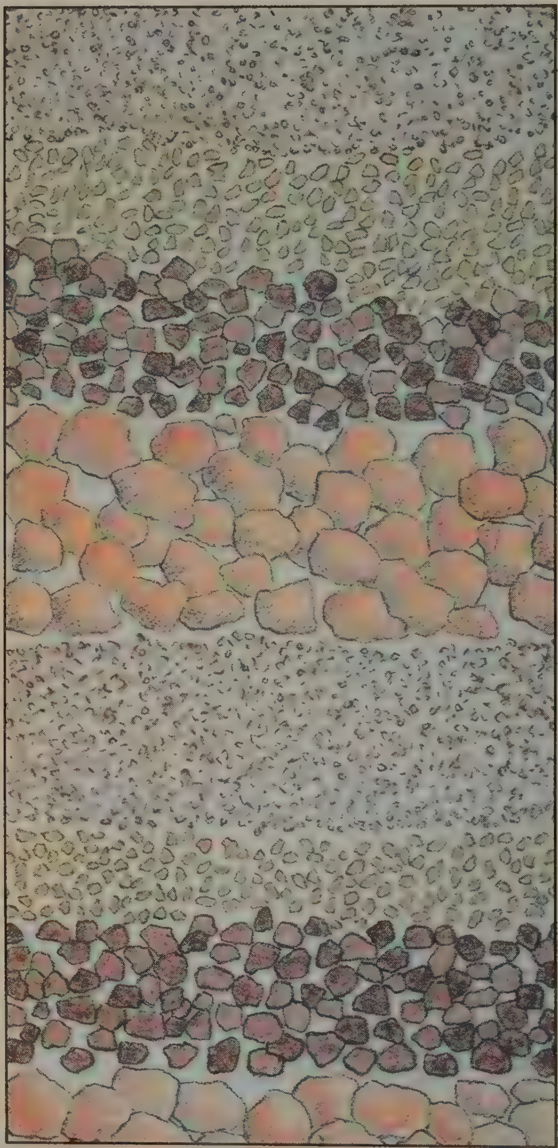
Transported soils have often determined the location of human civilizations. Farming has always been important because it provides the food needed for life. Due to heavy precipitation in the fall or spring, the volume of some rivers increases

Figure 9-19. The rich farmland in this valley is made up of transported soils. What natural agent of erosion transports soils from one place to another?

Library research

The ancient Egyptians relied on the Nile to flood each year to provide fertile land for farming. Prepare a report on the good and bad effects of rivers flooding.

Activity Analyzing a Core Sample



Materials

the model core sample shown on this page

Purpose

To examine a geologic core sample.

What to Do

1. Closely examine the core sample pictured in this activity. A core sample shows layers of rocks and soil laid down over time by weathering, erosion, and other means,.
2. Each layer represents a different period of deposition. Note the number and order of the deposits and the particles within each layer.

Questions

1. Are the oldest deposits at the top or the bottom of the core sample? Explain.
2. How many periods of deposition are represented in this model core sample?
3. Why might the layers show different particle sizes? (Hint: How might the size of the particles be related to water speed?)
4. At one point, the volume and speed of the water increased greatly. Which layer shows when this happened? Explain your answer.

Conclusion

How can looking at a core sample help you learn the geologic history of an area?

greatly. These rivers overflow their banks at least once a year. Figure 9-19 shows a valley where this happens. The soil in such a valley is very rich from material deposited by the overflowing river. Some of the earliest civilizations developed in such regions because the soil was good for farming.

Check yourself

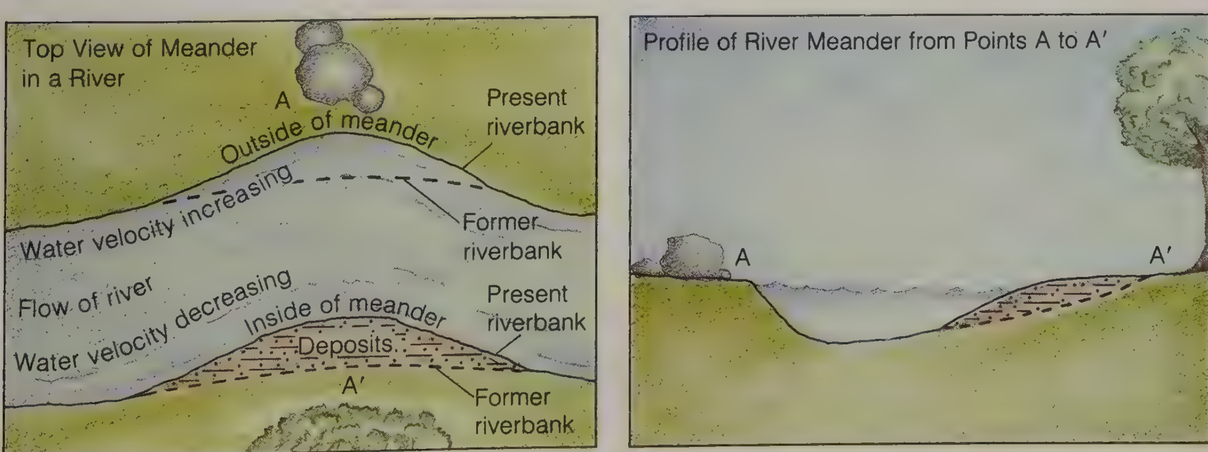
1. As a river begins to slow down, which particles settle first?
2. How do transported soils differ from residual soils?

Stream erosion and deposition

In some places in a stream or river, it is possible to observe evidence that erosion and deposition are both taking place at the same time. One such place is at a curve, or meander, in a river or stream, as shown in the top view in Figure 9-20.

When the water in a river reaches a meander, the speed of the water changes. Along the outside of the meander, the speed of the water increases. The increase in speed causes erosion. That is why the riverbank along the outside of the meander (labeled A in the diagram) is steeper than the riverbank along the inside. Along the outside of the meander, it is possible to observe material being eroded away from the riverbank.

Figure 9-20. Erosion is the dominant process on the outside of a meander. Deposition is the dominant process on the inside.



Activity Stream Erosion and Deposition Patterns

Materials

stream table, or large pan with a hole at one end

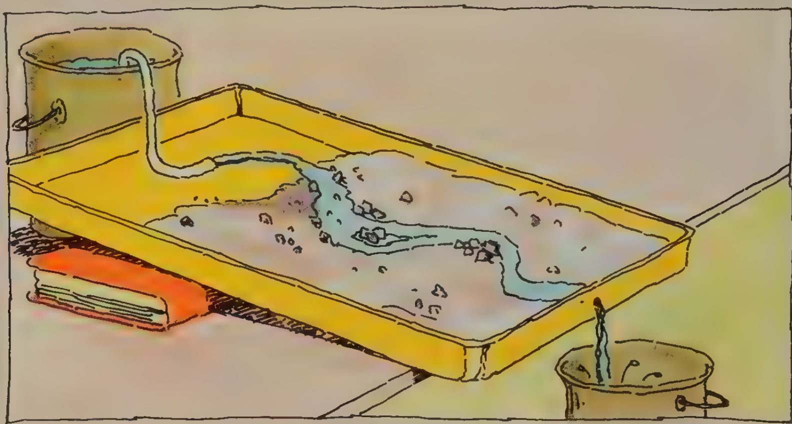
2 plastic buckets

rubber or plastic tubing

ordinary sand like that used in construction (soil works well but is messy)

books or blocks of wood to use as props

a few pebbles



Purpose

To learn where erosion and deposition patterns occur in a stream

What to Do

1. Spread a layer of sand or soil across the stream table as shown in the picture. Include a few pebbles. They will add interesting effects to the stream erosion.
2. Place the stream table on a very small slope. (A steep slope will inhibit the formation of meanders.)
3. Fill the bucket at least half full of water. (You can add more water later if necessary.)
4. Using the rubber or plastic tubing as a siphon, allow the water to run over the sand or soil, forming a model stream. Note the results.
5. After examining the effects of your stream, add a second siphon to the system and note the results.

Questions

1. What happens to the path of the stream as the water first flows from the original siphon?
2. As the water continues to flow, at what point(s) along the stream are particles being eroded? Why?
3. Where are particles being deposited? Why?
4. What size particles are eroded first? Why?
5. What effect does adding the second siphon have on erosion and deposition in the stream?

Conclusion

In general, where do erosion and deposition patterns occur in a stream? (Hint: See Figure 9-20 on the preceding page.)

Along the inside of the meander of a river or stream, the water slows down. This decrease in speed causes material to be deposited along the inside of the meander. That is why the riverbank along the inside of the meander slopes more gently than the steeper bank on the outside of the meander.

Check yourself

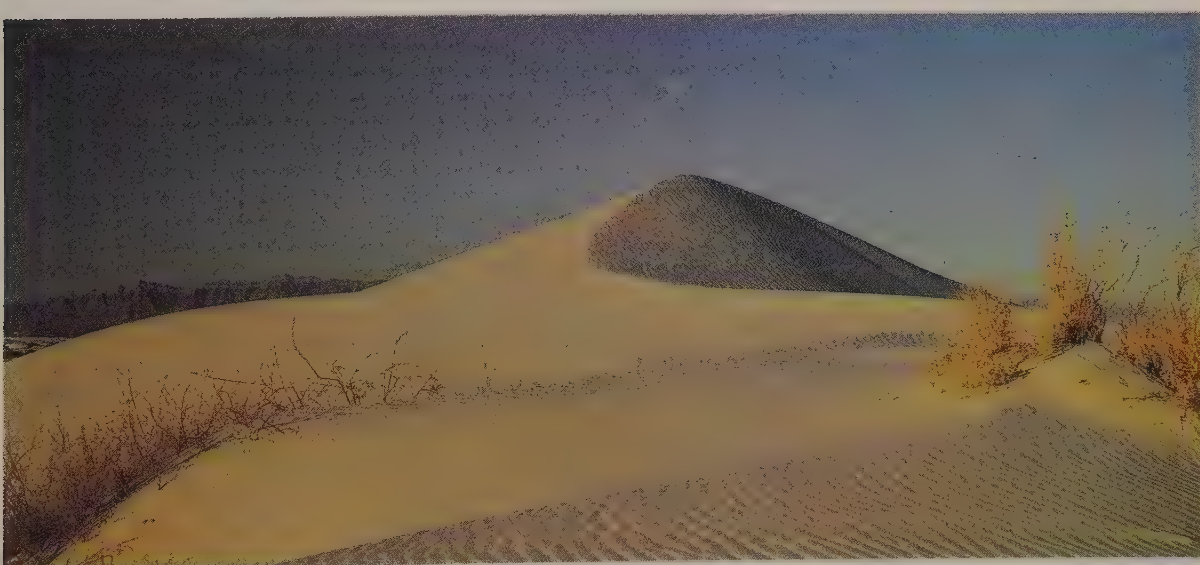
1. At a meander, where does the most erosion take place? Why?
2. How can both erosion and deposition take place at the same meander?

Deposition by wind

Winds can carry only very small particles. Therefore, deposits formed by winds contain particles that are all small and all about the same size. Also, the surfaces of particles carried by wind become scratched from striking each other.

On a worldwide basis, the effects of wind erosion and deposition are more limited than those of running water and glaciers. In a desert, however, it is often possible to see the distinctive effect of wind on the shaping of the landscape. The most

Figure 9-21. Sand dunes like this one at White Sands National Monument, New Mexico, are a wind-formed feature of a desert landscape.



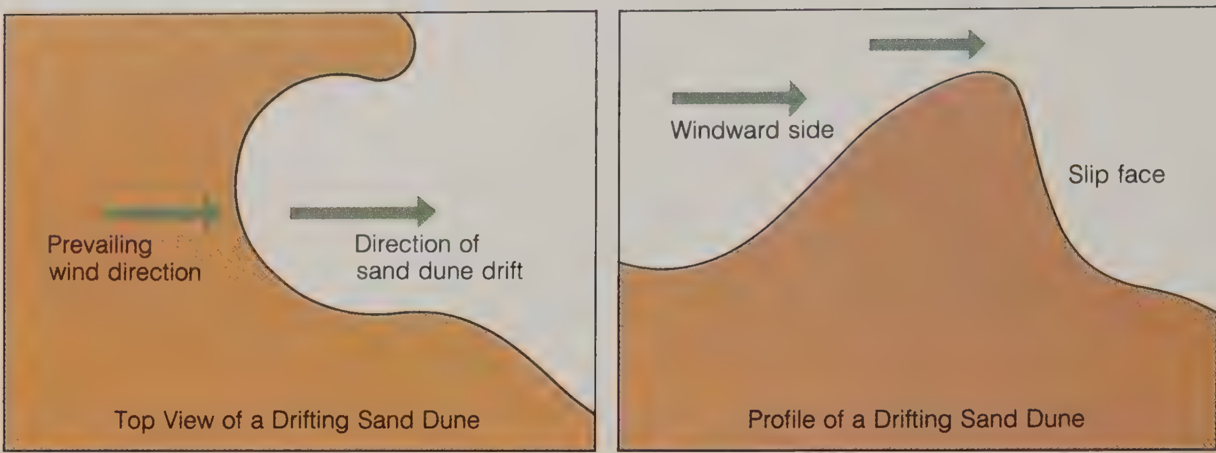


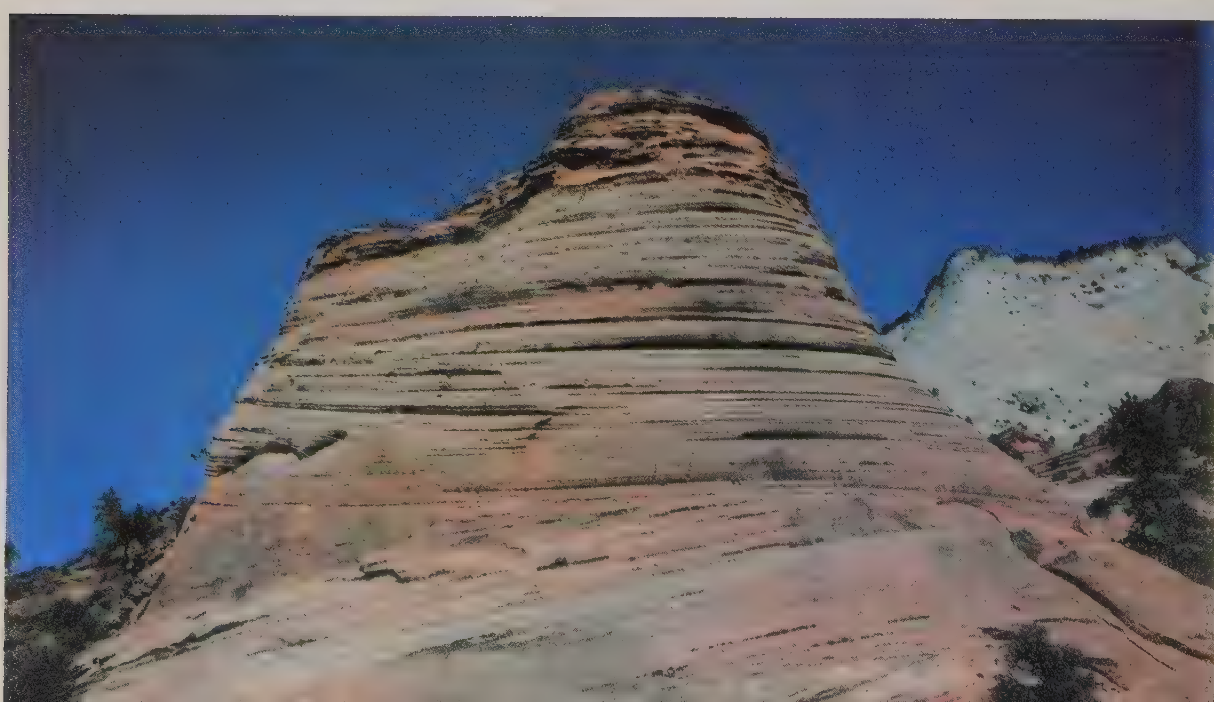
Figure 9-22. The steeper side of a sand dune, the side away from the wind, is called the slip face.

distinctive wind-formed feature of a desert landscape is the sand dune. As shown in Figure 9-21, the sand dune is commonly a crescent-shaped mound of sand.

Figure 9-22 illustrates how a sand dune drifts. Wind carries the sand up and over the gentle slope of the windward side of the sand dune. The sand is then deposited along the steeper slope of the **slip face,** which is the side away from the wind. This erosion and deposition causes the sand dune to "move" in the direction that the wind is blowing. This is what is meant when people refer to drifting sand dunes in a desert.

Figure 9-23. Why aren't the rock layers in this sandstone formation horizontal?

Figure 9-23 is a close-up photograph of rock layers in Utah's Zion National Park. These rock layers are really buried sand



dunes whose grains have been cemented into rock. If you look closely you can see the slanted sides of what formerly were sand dunes. The rock layers are hundreds of meters thick. Just imagine how long it must have taken for all of those sand dunes to build one on top of another.

Check yourself

1. What are three characteristics of particles deposited by the wind?
2. A sand dune involves both erosion and deposition. Explain.

Deposition by glaciers

Glacial deposits are easy to identify. They may contain a wide range of particle sizes—from tiny grains to large boulders. When a glacier moves, it picks up and carries particles of all sizes. This mixture is deposited when the glacier melts. Because the particles are carried frozen in the ice, they do not become rounded and sorted like particles carried by running water.

What size particles do glacial deposits contain?

The deposits of material made by advancing or retreating glaciers along their margins (or edges) are called **moraines.** The deposit formed at the foot or end of the glacier is called an **end moraine.** If that point is the farthest south that the glacier advanced, this end moraine is called a **terminal moraine.** At some locations in the United States, there are terminal moraine deposits with a thickness of 30 m or more.

Sometimes a **glacial lobe** will form along the side of a continental glacier. This lobe of ice, which sticks out like a tongue from the main ice mass, may be more than 30 km wide.

Library research

Find out about a present-day glacier. How does the data you discover relate to the ideas about prehistoric glacial deposition presented in this section?

The melting ice at the foot of the glacier forms rivers and streams that carry with them the smaller particles. Most of this material is deposited and sorted within a few kilometers of the foot of the glacier, as the speed of the running water decreases. This area of deposition is called an **outwash plain.**

What is an outwash plain?

Figure 9-24 shows the outwash plain at the foot of a glacier. Most of the earth material, including all the large particles, is

Activity Comparing Core Samples

Materials

the model core samples shown on this page

Purpose

To infer geologic history by comparing two model core samples.

What to Do

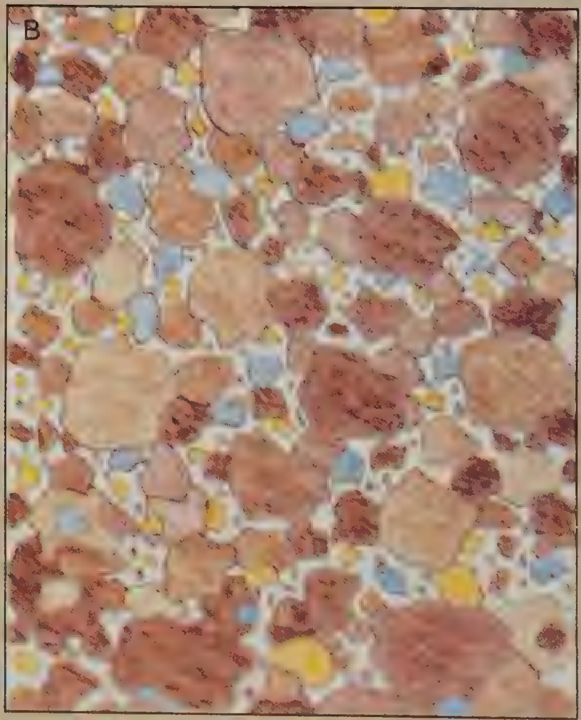
1. The two model core samples on this page (labeled A and B) represent samples taken from two different locations. At one location the major agent that shaped the landscape was glaciers. At the other, the major agent was running water. You are to figure out which core sample shows the work of which agent.
2. Examine the material in each sample. Record all observations that you think might help.

Questions

1. How do the particles in each sample compare in arrangement, size, and sorting?
2. Which sample came from a landscape formed by glaciers? Explain your reasoning.
3. Which sample came from a landscape formed by running water? Explain your reasoning.

Conclusion

One of the first steps to take in interpreting the history of a landscape is to analyze any deposits that are present. Why is this so important?



deposited at the foot of the glacier. The smaller particles are carried away from the foot of the glacier and deposited on the outwash plain, which has a gentle slope.

The material in a glacial moraine is called **till.** Till can easily be distinguished from river deposits because it contains such a wide variety of unsorted and unrounded particles that range in size anywhere from boulders to tiny fragments.

The material that is carried away from the glacial moraine by meltwater and deposited in the outwash plain is called **stratified drift.** Stratified drift is similar to river deposits in that the particles are well sorted. As the meltwater slows down, the largest particles settle out first. Farther out on the outwash plain, particles are deposited in increasingly smaller size.

In what order are particles deposited on an outwash plain?

Continental glaciers produce many interesting and unique landscape features. Figure 9-25 shows a series of **drumlins,** which are smoothly rounded hills of glacial till. From the air, drumlins are more or less teardrop-shaped. The narrow end of the "teardrop" points in the direction in which the glacier was moving. (The word *drumlin* comes from the Irish word *druim,* which means "a narrow ridge.")

How drumlins formed is something of a mystery. One theory suggests that drumlins solidified from a fluid mass of rock, soil, ice, and water that flows along with and under an advancing glacier. Increases in pressure, caused perhaps by rocks or other obstructions on the earth's surface, "squeeze" the water

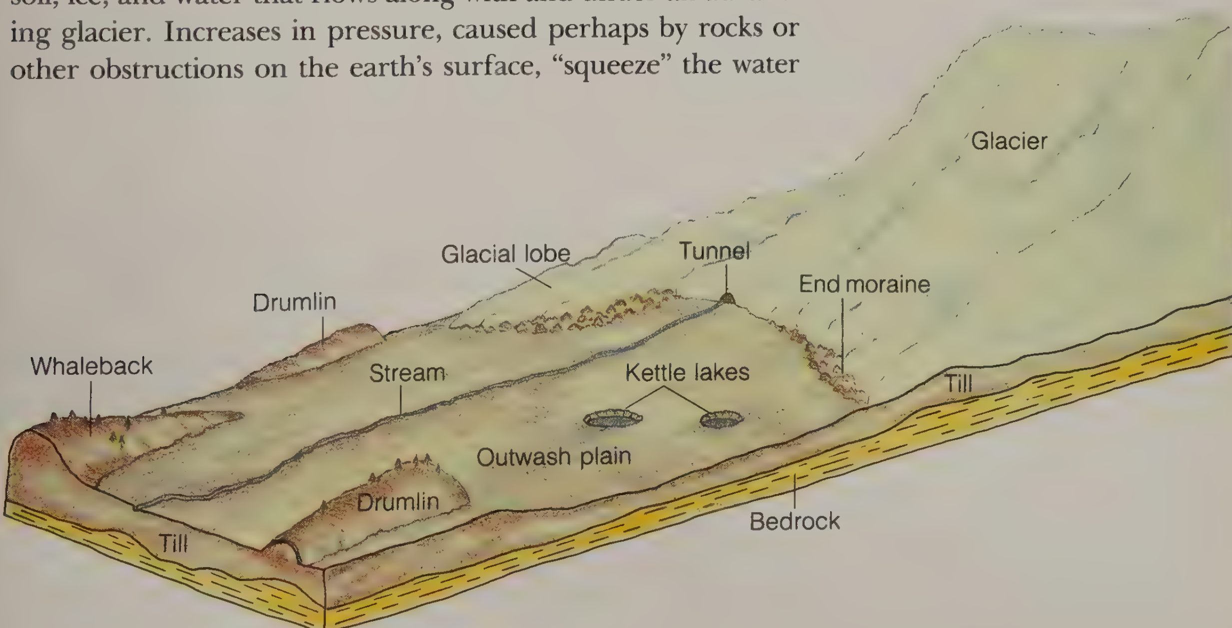


Figure 9-24. How do the particles deposited at the foot of a glacier differ from those deposited on the outwash plain?

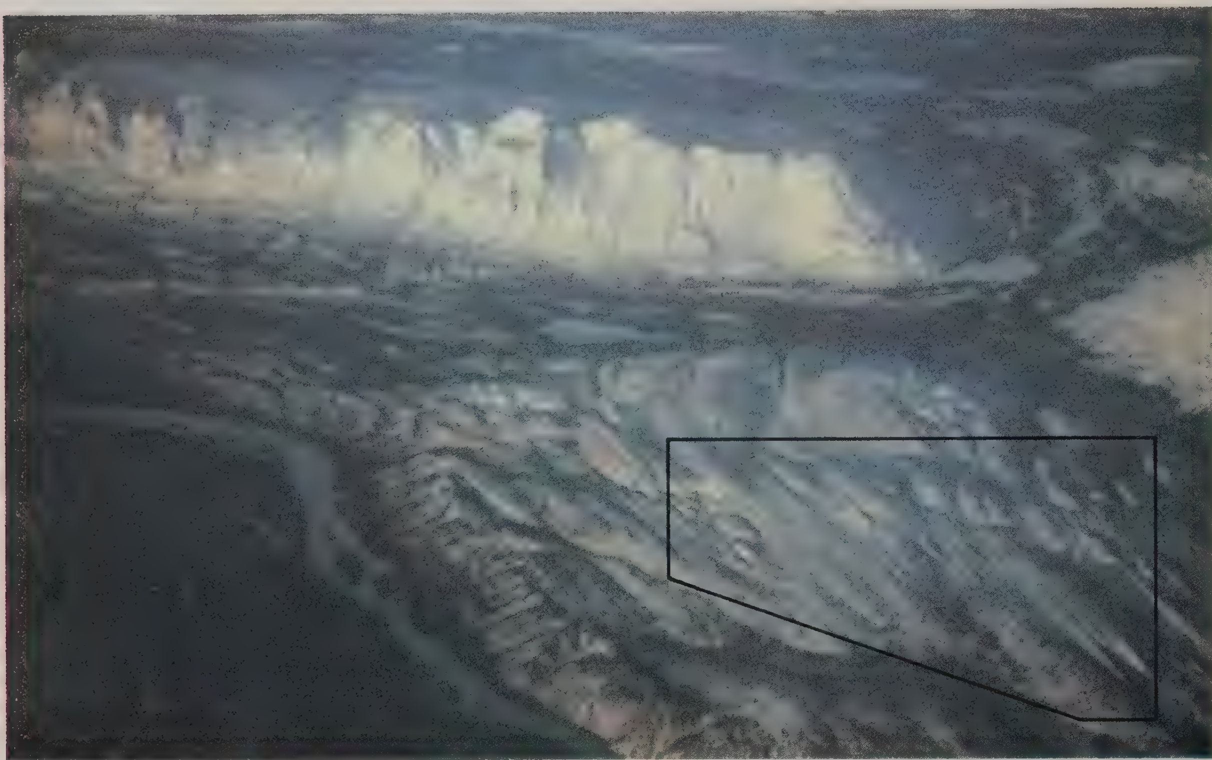


Figure 9-25. These drumlins are located near Mount McKinley, Alaska. In which direction did the glacial ice move?

out of the fluid mass and cause it to solidify. The abrasive action caused by the glacier's continued movement over this solid mass would tend to explain why the surface of this kind of glacial deposit is so well rounded.

Sometimes large blocks of ice break off from a glacier and become buried under large masses of overlying deposits. When the ice melts, a large cavity in the deposit is left behind. The cavity, which fills with water from the melting ice, forms a **kettle lake.** Kettle lakes are usually round and very deep.

Check yourself

1. River deposits are said to be well sorted. How are they sorted? What causes the sorting?
2. Compare a moraine with stratified drift. How are they similar? How are they different?

Section 3 Review Chapter 9

Check Your Vocabulary

deposition	residual soils
drumlin	slip face
end moraine	sorting
glacial lobe	stratified drift
kettle lake	terminal moraine
moraine	till
outwash plain	transported soils

Match each term above with the numbered phrase that best describes it.

1. The process whereby particles and fragments are deposited by an agent of erosion
2. The process by which fragments of earth materials are deposited from running water in order of size
3. The side of a dune away from the wind
4. The deposit of material made along its margins by an advancing or retreating glacier
5. A deposit formed at the foot of a glacier
6. The deposit that marks the farthest advance of a glacier
7. A tongue-like mass of ice that sticks out from the main mass of a glacier
8. Soils that remain near the bedrock from which they have weathered
9. A gently sloping area of deposition at the foot of a glacier
10. The material in a glacial moraine
11. Sorted particles that have settled out of meltwater on an outwash plain
12. A teardrop-shaped hill of glacial till
13. A lake that formed when a large block of buried glacial ice melted
14. Soils formed from eroded materials

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Deposits formed from _?_ contain layers of different particle sizes.
   a) continental glaciers
   b) valley glaciers
   c) landslides
   d) running water
2. Sorting takes place in moving water because of differing _?_ of the water.
   a) temperatures
   b) volume and speed
   c) solutions
   d) lobes
3. Along the outside of a meander, the speed of the water _?_.
   a) decreases a little
   b) increases
   c) decreases noticeably
   d) does not change
4. Particles deposited by wind are _?_.
   a) large
   b) unsorted
   c) all about the same size
   d) unscratched

Check Your Understanding

1. How are particles carried along by a river deposited where a river enters the sea? Why does this happen?
2. How do the river banks on either side of a meander compare? How can this difference be explained?
3. How can a sand dune drift?
4. Why are glacial deposits easy to identify?
5. Why could the sorting of glacial deposits take place only on the outwash plain?

Chapter 9 Review

Concept Summary

Weathering is the breaking down and wearing away of earth materials.

- ☐ Weathering can change the size of a material, the substance of a material, or both.
- ☐ Soils are formed from the weathering of rock.

Physical weathering occurs when earth materials are reduced in size.

- ☐ Physical weathering is caused by temperature changes and the abrasion that occurs when rock fragments strike each other.

Chemical weathering occurs when new substances are formed from earth materials.

- ☐ Chemical weathering often takes place at the same time as physical weathering.

Erosion involves the transport of weathered earth materials from one place to another.

- ☐ Four common agents of erosion are running water, wind, glaciers, and gravity.
- ☐ Particles carried by erosion vary greatly in size—from substances dissolved in water to large boulders.
- ☐ Running water is the dominant agent of erosion.
- ☐ Most erosion involves more than one agent.
- ☐ In addition to being an agent of erosion, gravity is also the underlying force behind all other forms of erosion.

Deposition occurs when particles of earth materials are deposited by an agent of erosion.

- ☐ Sorting of particles by size indicates deposition from running water.
- ☐ Unsorted particles that vary greatly in size indicate a glacial deposit.

Putting It All Together

1. Explain the formation of beach sand from a sandstone cliff. Include physical and chemical weathering in your explanation.
2. Explain the formation of a fully developed soil profile.
3. Give examples of physical and chemical weathering that occur where you live.
4. What is the relationship between weathering and erosion before the erosional process and during the erosional process?
5. What erosional processes take place on a desert? What agents of erosion are involved?
6. Compare a flood plain and a delta. How are they similar? How are they different?
7. Explain why sorting indicates deposition by running water.
8. Draw a diagram that shows what happens along the inside and outside curves of a meander. Why does this happen?
9. Draw a profile of a drifting sand dune, distinguishing between the windward side and the slip face.
10. Draw a diagram that shows the relative positions of end moraine, stratified drift, and drumlins. Then, with a colored pencil, show where the glacier would have been before it melted.

Apply Your Knowledge

1. How would the kind of soil that forms near the North Pole compare with the kind of soil that forms in a forest?
2. Describe what happens to the soil in a flowerpot after continued watering. What can be done so that plant growth is not affected?
3. When a sandstone cliff weathers, what happens to the minerals that held the particles of sand together?
4. How can scientists infer that there have been many different periods of deposition in a river delta?
5. What can scientists infer about ice sheets once covering areas of North America?

Find Out on Your Own

1. Find three different kinds of soils that formed naturally near where you live. How do the soils differ from each other? What might explain the differences?
2. Find examples of erosion that are taking place near where you live. When does the erosion occur? What if anything is being done to prevent the erosion?
3. Find examples of deposition that are taking place near where you live. What is causing the deposition? How long can the deposits be expected to remain? What will probably happen to the deposits?
4. What about the geology of the area where you live? What landscape formations are the result of erosion? What formations are the result of deposition?
5. What if anything is being done that affects erosion and deposition where you live? Why is this being done?

Reading Further

Bates, D. E. B., and J. F. Kirkaldy. *Field Geology in Color.* New York: Arco Publishing Company, Inc., 1977.

A field guide to geologic formations. Color photographs of field occurrences vary from close-ups of mud cracks to distance shots of large formations. A handy reference book to have on a field trip.

Doolittle, Jerome, and the Editors of Time-Life Books. *Canyons and Mesas.* New York: Time Incorporated, 1974. Part of the Time-Life American Wilderness Series.

A guided tour of a land area whose land formations speak for themselves. Also includes descriptions of the earth processes that shaped the unforgettable sights of this vast wilderness.

Jones, Philip. *The Forces of Nature.* Chicago: Childrens Press, 1982.

An interesting account of the formation of the earth. Also describes changes of weather: clouds, rain, wind, snow, ice, thunder, and lightning. Beautiful photography of ice crystals.

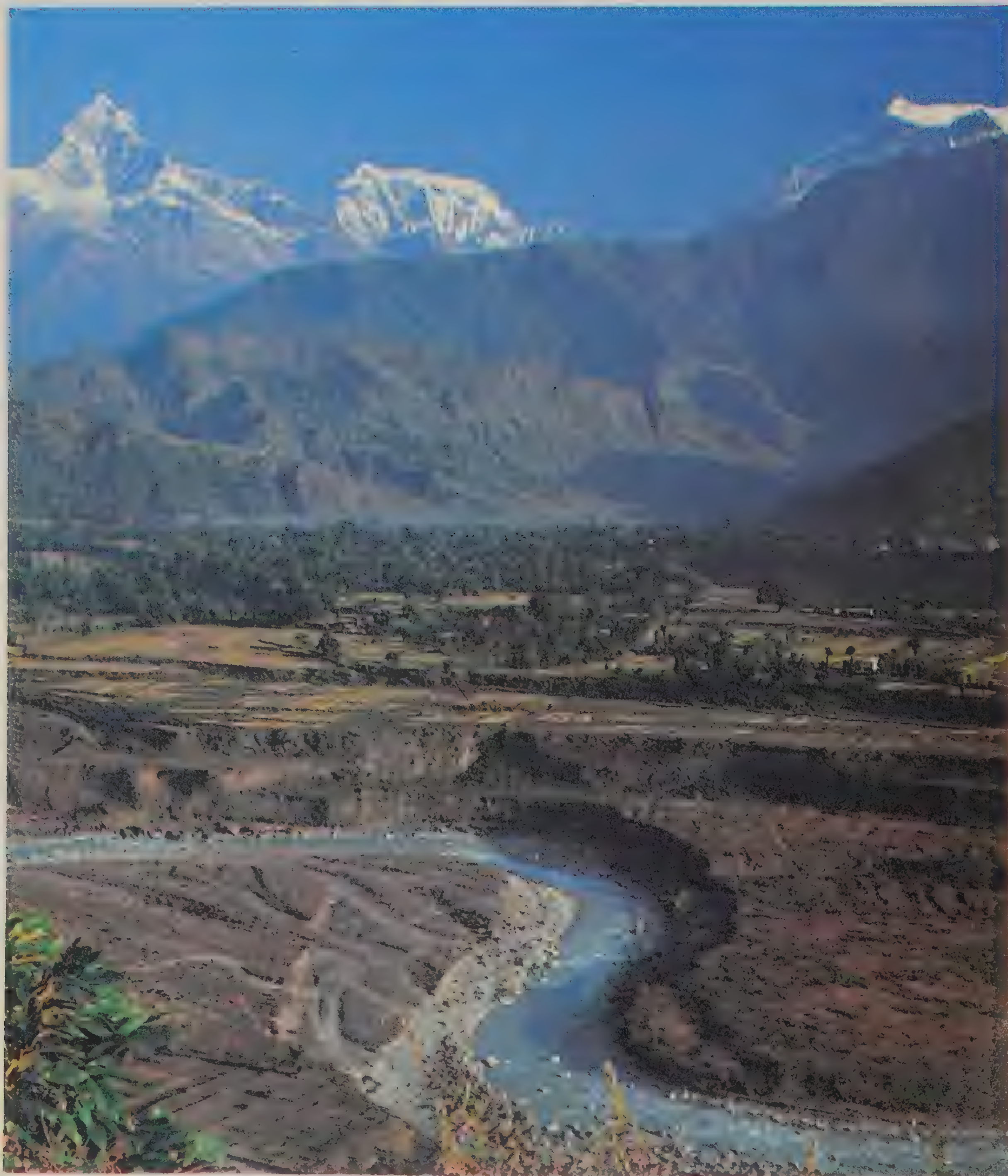
Marcus, Elizabeth. *All About Mountains and Volcanoes.* Mahwah, NJ: Troll, 1984.

An easy-to-read book that explains how mountains are formed and how they affect weather. Also includes a selection on erosion. Excellent diagrams.

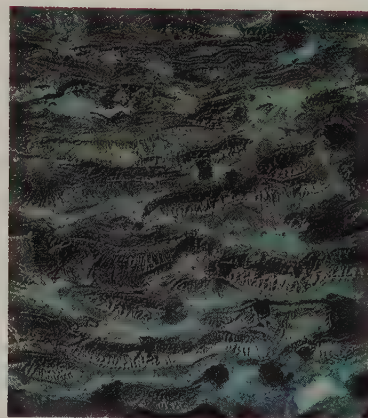
Page, Lou Williams. *Ideas from Geology.* Menlo Park, California: Addison-Wesley Publishing Company, 1973.

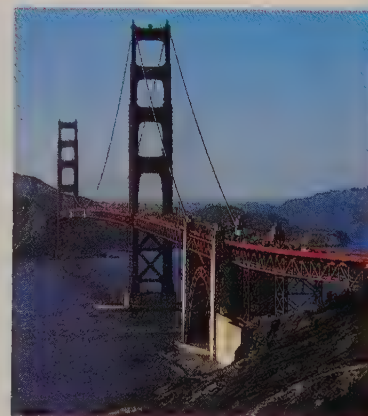
Photographs of minerals, sand grains, and boulders and cross sections of rock formations that you will recognize because of your familiarity with earth science. Diagrams that explain key concepts. Mature, informative, scientific text that is readable, interesting, and professional.

Chapter 10



The Restless Crust





Section 1
Volcanoes

To an observer viewing some of the earth's landforms, the earth's crust may appear to be solid and stable. But deep below the surface, there is pressure that is great enough to bend rock and heat that is great enough to melt rock.

Sometimes this underground activity merely changes the earth's crustal rocks. At other times, however, this below-the-surface activity breaks through to the earth's surface and is then known as volcanic activity, which can vary greatly in form and intensity.

Section 2
Stress, Structure, and Earthquakes

Rocks in the earth's crust will melt when subjected to great heat. Rocks in the earth's crust will also fold and bend, break and slide because of pressures that build up within the earth's crust.

Sometimes the pressure is released through many small earthquakes. At other times, however, pressure in the earth's crust continues to build, and the pressure can be released only through a major earthquake.

Section 3
Plate Tectonics

Earthquakes and volcanoes are very powerful, and they can cause great damage. Scientists, therefore, are looking for ways to predict when a major eruption or earthquake might occur.

Earthquakes and volcanoes are much more likely to occur in certain parts of the world than in others. The Pacific Ocean, for example, is circled by areas of volcanism and faulting. Beneath the Atlantic Ocean there is another area of active volcanoes.

The mountains pictured on the facing page are part of the Himalayan range that rises between India and China. The Himalayas are the highest landforms on the earth. What do you think might be causes for the earth's mountain ranges, which are among its most beautiful and spectacular landforms?

Volcanoes Section 1

Section 1 of Chapter 10 is divided into four parts:

The power of a major volcanic eruption

Why some eruptions are so violent

Volcanic landforms

Where volcanoes occur

Figure 10-1. This volcano is located on Heimaey Island, Iceland. What two causes of volcanic activity exist within the earth's crust?

Of all the earth processes, volcanic activity is certainly among the most powerful. By means of volcanic activity, people are able to witness the active transfer of earth materials and the active re-formation of the earth's surface. By means of volcanic activity, people are able to get some idea of the tremendous heat and pressure that exist within the earth's crust, where the heat is great enough to melt rock and the pressure is great enough to blow the top off a mountain.

The power of a major volcanic eruption

History contains accounts of over five hundred major volcanic eruptions and thousands of minor eruptions. Some have been described in great detail. Some have been photographed. Some have happened so recently that the details can be obtained directly from eyewitnesses.

The eruptions of Mount Mazama, Mount Vesuvius, Krakatau, Mount Pelée, Mount Lassen, Parícutin, and Mount St. Helens provide examples of the power of a major volcanic eruption. In addition, you can use your library as a resource for other accounts of volcanic eruptions.

Mount Mazama. The Cascade Mountains of the northwestern United States have been the site of much volcanic activity. Of all the volcanoes in the Cascade Range (which extends from northern California to Canada), the one that may have had the largest eruption was probably Mount Mazama (muh-ZAH′-muh) in southern Oregon.

Prior to its eruption about 6600 years ago, Mount Mazama had a height of over 1800 meters. During that eruption, 49 cubic km of mostly ash and pumice were blown into the air and extruded (forced or pushed) out and down the sides, spreading over 896 000 square km. Beneath the mountain, the magma chamber that had been emptying during the eruption became even larger as the remaining magma drained back into the depths of the earth. The mountaintop collapsed into the empty magma chamber, leaving a large circular depression 916 m in diameter.

Through eruption and collapse, Mount Mazama lost 70 cubic km of its top. The remaining rim now rises only 450 m

Figure 10-2. In some eruptions, the mountaintop collapses into the empty portions of the magma chamber beneath the mountain, forming a caldera.

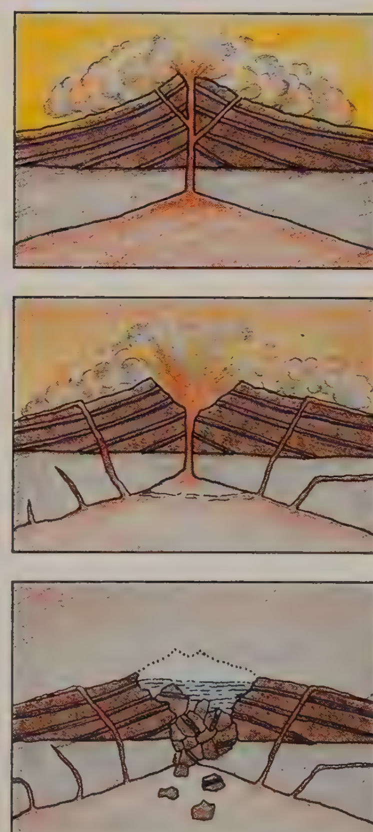


Figure 10-3. Crater Lake is located in a caldera that formed after a violent eruption of Mount Mazama. How long ago did that eruption occur?

What is the hole in a collapsed crater called?

above the surrounding countryside. This type of a collapsed volcanic crater is called a **caldera** (kal-DIR′-uh). Three small volcanic cones were later formed in the floor of the collapsed crater. Water has since accumulated to a depth of about 610 m inside the caldera. The area is known today as Crater Lake National Park.

Mount Vesuvius. A seventeen-year-old young man by the name of Pliny (PLIN′-ee) has provided us with an eyewitness account of the eruption of Mount Vesuvius (vuh-SOO′-vee-is) on August 24, A. D. 79. The eruption of Mount Vesuvius took place across the bay from present-day Naples. In that A. D. 79 eruption, three towns were buried under more than 18 m of heated mud and ash. About ten percent of the population of the three towns was killed during the eruption.

Krakatau. In 1883, a volcanic mountain erupted on Krakatau (krah′-kah-TOW′), a small island between Java and Sumatra in present-day Indonesia. The noise from the eruption was heard as far away as Australia. The force of the eruption blew off much of the mountain and created a large caldera (a modern

example of what probably happened to Mount Mazama 5600 years earlier). The eruption also produced a huge dust cloud that circled the earth at altitudes of over twenty-seven kilometers. For three years following the eruption, the volcanic dust cloud caused the solar radiation level in Europe to be ten percent below average. The dust cloud also provided years of spectacular sunsets all over the earth.

Mount Pelée. In 1902, on the island of Martinique in the West Indies, Mount Pelée (puh-LAY′) erupted. The eruption did not come out of the top of the volcanic mountain because the top was plugged with volcanic rock from a previous eruption. Instead, the eruption broke through a weakened side of the volcano. Hot ash, cinders, gas, and rock rubble roared down the slope toward the seaport of St. Pierre at a speed of nearly 90 km per hour. Mount Pelée's eruption killed 28 000 people. Only two people survived. One of the two survivors was a prisoner in a dungeon, and the other was in his basement at the time of the eruption.

Library research

Find and compare eyewitness accounts of several major volcanic eruptions. Which account do you find the most interesting? Why?

Figure 10-4. When Mount Pelée (the mountain in the background) erupted on May 8, 1902, 28 000 people were living in the seaport of St. Pierre (Martinique, West Indies). How many people survived?

What is a lateral eruption?

Mount Lassen. In 1914, another period of volcanic activity took place in the Cascade Mountains. A **lateral eruption** (an eruption from the side of the mountain) took place on Mount Lassen, located in northern California.

Mount Lassen's eruptive period lasted from 1914 to 1921. An ash cloud rose over 9000 m. Several centimeters of volcanic ash accumulated on the streets of Reno, Nevada, 216 km away. The lateral eruption extended for several kilometers away from the mountain and involved lava that spilled down the sides of the mountain, melted snow, and created floods filled with large volcanic boulders.

How destructive was the eruption of Parícutin?

Parícutin. In February, 1943, a volcano named Parícutin (pah-REE′-koo-ten′) began as a small opening in a farmer's field in Mexico. At first, Parícutin was a curiosity that drew visitors and attracted scientific interest. As the volcanic material grew into a mountain, however, the farmer had to abandon the farm. In time, people in nearby towns had to leave their homes because the entire area became filled with ashes and lava. Parícutin was no longer a curiosity. It had destroyed two towns and the surrounding countryside. In one town, only the top of a church steeple showed above the thick lava deposits.

Mount St. Helens. In May, 1980, an eruption of Mount St. Helens in the state of Washington set off huge ash falls, mudslides, and floods. More than six people were killed, and property damage was set at $2.7 billion.

In one large explosion, the upper 400 m (about 4 cubic km) of Mount St. Helens blew away. Much of the explosion propelled broken rock, ash, and mud laterally down the side of the mountain, scorching and smothering the land and every living thing in its path. The debris filled in valleys and created dams. As a result, the level of Spirit Lake near the base of Mount St. Helens is about 115 m higher than it was before the eruption.

The blast from the eruption stripped trees of limbs and laid the trees over onto the ground. From high in the air, the ground appeared covered with matchsticks. But these matchsticks represented nearly 590 square km of formerly thickly forested land.

Mount St. Helens has had a long history of activity. Four hundred years ago, volcanic activity reshaped the cone into one

of the most symmetrically shaped cones in the world. Between 1831 and 1957, the mountain was again active with minor eruptions. However, even though the volcano had been intermittently active, the 1980 eruption was unexpectedly violent.

Figure 10-5. The bleak landscape of the Mount St. Helens blast area is a grim reminder of the death-dealing nature of volcanoes.

An area of over 400 square km of the Mount St. Helens region has been designated a National Volcanic Monument and attracts many visitors. The bleak landscape has an eerie quality and is a reminder of the awesome power and death-dealing nature of volcanoes.

Loss of life and property is common with volcanic eruptions. But even with all the dangers, people often repopulate devastated landscapes. The slopes of Mount Vesuvius, for example, have people living there today.

Check yourself

1. How do volcanic eruptions in inhabited areas affect people?
2. How far into the atmosphere can volcanic eruptions reach? Give an example.
3. List and describe three examples of major volcanic eruptions.

Why some eruptions are so violent

Volcanic activity includes all earth processes in which molten rock, gases, or fragments of solid material come out of a **vent,**

which is an opening in the earth's crust. (As you may recall, molten rock below the surface of the earth is called **magma**; molten rock on the surface of the earth is called **lava.**) Sometimes the lava or fragments spread out almost flat. Sometimes the volcanic material from the vent builds up to form a mountain. Either the vent or the mountain is known as a **volcano.**

What are four sources of heat within the earth?

Volcanic material is hot. Gases and lava may reach 1200°C. The source of heat within the earth can be from several different earth processes. One source would be heat left over from when the earth was first formed. A second source of heat would be from the friction of rocks bending or sliding past other rocks deep within the earth. A third source is radioactive elements found within the earth that undergo spontaneous change and release heat. Other sources such as chemical reactions associated with the forming and re-forming of different minerals may contribute minor amounts of heat.

Library research

Find out more about the causes and effects of the earth's interior heat.

One of the concerns of people has been the violent nature of volcanoes. The Valley of 10,000 Smokes in Alaska was at one time a volcanic mountain, Mount Katmai (KAT′-mī). In 1912, Mount Katmai exploded, leaving a huge valley with thousands of fumaroles. A **fumarole** (FYOO′-muh-rōl′) is a volcanic vent or opening that gases and smoke come out of.

What causes some eruptions, like Mount Katmai and Mount St. Helens, to be violent and others, like those of Hawaii or Iceland, to be relatively quiet? Usually three variables account for the differences in violence.

1. The first factor is the viscosity of the lava. **Viscosity** (vis-KOS′-uh-tee) is a measure of how easily a liquid flows. Volcanoes with a highly viscous lava (in other words, with lava that flows very slowly) often tend to have more violent eruptions.

2. The second factor is the water content of the lava. The presence of superheated steam tends to make the eruption more violent.

3. The third factor is the chemical composition of the lava. If the chemical composition is similar to the continental rock type granite (over 60% silica), then the eruption tends to be more violent. If the lava has the chemical composition of basalt (40% silica), as in oceanic crustal rocks, then the eruption tends to be less explosive.

Figure 10-6. These erosion patterns were photographed in the Valley of the 10,000 Smokes, Alaska. How and when was this valley formed?

Check yourself

1. What earth processes are considered volcanic activities?
2. List the three major sources of heat that contribute to the heat in the earth.
3. How hot are volcanic gases and molten rock?

Volcanic landforms

Volcanic eruptions can develop into three different types of volcanic mountains, depending on the nature of the volcanic material. The three types of volcanic mountains are shield cones, cinder cones, and composite cones.

A **shield cone** is a volcanic mountain that is built almost entirely of lava flow. The slopes of a shield cone volcano are very gentle and rounded like a warrior's shield. (The slopes of such a volcano have an average angle of 2°.) The islands of Iceland and the Hawaiian Islands are examples of shield cones. The island of Hawaii is a shield cone volcano that rises from the ocean floor. That volcano is more than 10 km high from its base on the ocean bottom to its highest point above the sea.

A **cinder cone** is a volcanic mountain that is built entirely of volcanic cinders and ashes. Cinder cones are small (usually less than 450 m high) and have steep sides. The slopes of such a volcano have an average angle between 30° and 40°. Examples of cinder cones are the volcanic cones of Parícutin in Mexico, Cerro Negro in Nicaragua, and Wizard Island in Crater Lake, Oregon.

Activity Inferring Lava Viscosity

Materials

specimens of basalt from two different kinds of lava flows: aa (AH′-ah) and pahoehoe (puh-H̄O′-ee-hō′-ee)

Purpose

To infer lava viscosity from volcanic materials.

What to Do

1. Examine your lava specimens. They are made of basalt, one of the most widespread of volcanic igneous rocks. Basalt rock occurs as massive lava flows, which can accumulate to the astounding size of large landforms known as plateau basalts, or basalt floods.
2. Basalts assume different shapes and textures as they solidify. Aa lava is cindery, with sharp edges and lots of small holes. Pahoehoe lava appears smooth and ropy or billowy. Note the textures of your particular specimens.

Questions

1. Which kind of basalt lava indicates a less viscous (that is, more freely flowing) lava?
2. Which kind indicates a more viscous (less freely flowing) lava?
3. When lava cools, it becomes more viscous. Which kind of lava do you think forms closer to a volcanic fissure or vent? Explain.

Conclusion

What does looking at basalt lava tell you about its viscosity?

A

B

C

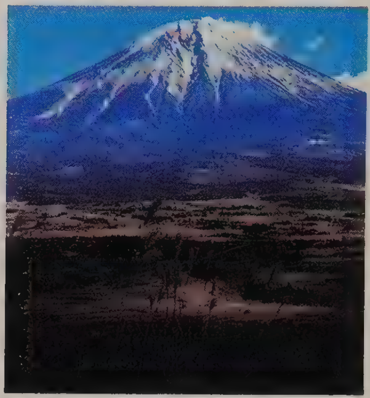


Figure 10-7. (A) Mauna Kea, Hawaii, shield cone. (B) Cinder cone in a volcanic field near Sonora, Mexico. (C) Mount Fuji, Japan, composite cone.

A **composite cone** is built of alternate layers of lava flows and volcanic cinders and ashes. Composite cones are volcanic mountains with beautifully symmetrical shapes. Mount Fuji in Japan and Mount Shasta in California are two examples of composite cone volcanoes. Mount St. Helens, a composite cone, had a more symmetrical shape before its last eruption.

Composite cone volcanoes can reach 4 km in height. The gentle slopes near the base of a composite cone are generally lava flows. These lower slopes have an average angle of 5°. The steeper parts of a composite cone contain larger percentages of cinders and ash. The upper slopes have an average angle of 30°.

What are plateau basalts?

Some volcanic activity does not produce a cone. Sometimes the lava flows from a **fissure** (FISH′-er), which is a long crack in the ground. Thick buildups of horizontal layers of basalt may form as a result of lava flows from fissures in the ground. These types of thick deposits on the continents are called **plateau basalts.** Much of eastern Washington and Oregon and parts of Idaho are covered by plateau basalts. In India, the Deccan plateau basalts cover more than 500 000 square kilometers. In South America, the Parana plateau basalts of Brazil and Paraguay cover more than 750 000 square kilometers.

Check yourself

1. List examples of three types of volcanic mountains.
2. What are the relative sizes of the three types of volcanic mountains?
3. How do plateau basalts form?
4. List three examples of areas of plateau basalts, and indicate their size.

Where volcanoes occur

Volcanic activity is more likely to occur in certain regions of the earth than in others. Two regions of volcanic activity are the Circum-Pacific Ring of Fire and the mid-ocean ridge.

The Circum-Pacific Ring of Fire. Many volcanoes are located around the Pacific Ocean. This entire group of volcanoes makes up what is called the **Circum-Pacific Ring of Fire.** The Latin word *circum* means around. And a glance at Figure 10-8 will show you why this group of volcanoes is called a ring.

The Circum-Pacific Ring of Fire includes the volcanic mountains near the edges of North America, Central America, and South America. It also includes the volcanic islands that are found in the North and West Pacific. These volcanic islands form curve-shaped groups called **island arcs.** The Mariana Islands and Japan in the West Pacific and the Aleutian Islands in the North Pacific are examples of island arcs. The Aleutians curve south and west from Alaska and form the southern boundary of the Bering Sea.

There is a relationship between the volcanoes of the Circum-Pacific Ring of Fire and trenches in the Pacific Ocean. Along the ocean bottom, volcanoes of the Circum-Pacific Ring of Fire

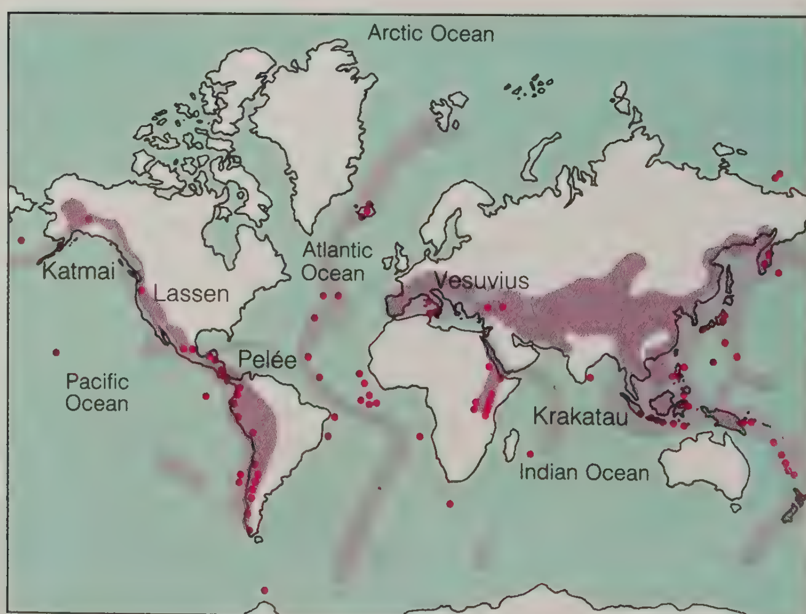


Figure 10-8. Many volcanoes are located around the edge of the Pacific Ocean and form what is called the Circum-Pacific Ring of Fire. Where are many volcanoes of the Atlantic Ocean?

are found near trenches. The volcanoes of the Aleutian Islands, for example, are along the Aleutian Trench, which is 3700 km long and 7.7 km deep. On the continent of South America, the volcanoes of the Andes Mountains are parallel to the Peru-Chile Trench. In Central America, the volcanoes are near the Middle America Trench.

Figure 10-9. Surtsey, off the southern coast of Iceland, is located along the mid-ocean ridge, a site of much volcanic activity.

The mid-ocean ridge. Much volcanic activity takes place along the mid-ocean ridge. The **mid-ocean ridge** is a system of tall, rugged, submerged mountains that form the single most dominant feature of the ocean bottoms. As shown in Figure 8-9 (page 380), the mid-ocean ridge extends down the center of the Atlantic Ocean, around the tip of Africa, and into the Indian Ocean. In the Indian Ocean, the mid-ocean ridge splits into a Y shape. One part of the Y extends northward toward the Gulf of Aden where it splits into a Red Sea branch and an African rift system branch. The other part extends southeastward—passing south of Australia, across the southern Pacific Ocean, and up toward Central America. Active volcanoes are found along many parts of this mid-ocean ridge system. Although most of the volcanic activity along the ridge is below the ocean's surface, some volcanic mountains form islands like Iceland and the Azores in the Atlantic Ocean.

What happens to the mid-ocean ridge when it reaches the Indian Ocean?

Check yourself

1. Describe the Circum-Pacific Ring of Fire.
2. Describe the volcanic nature of the mid-ocean ridge.
3. What do the Japanese Islands and the Aleutian Islands have in common?

Activity Reconstructing the Topography of a Volcanic Cone

Materials

the three topographic maps reproduced in the Appendix

graph paper

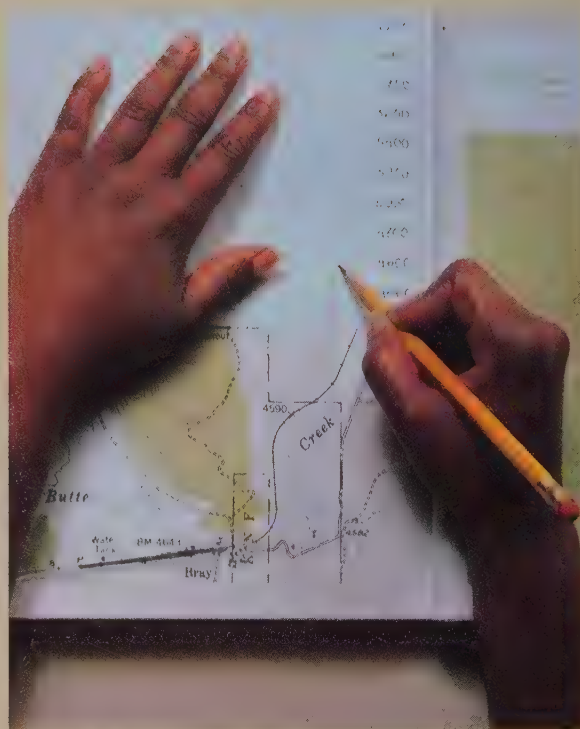
pencil

Purpose

To learn to translate a topographic map of a volcanic cone into a profile view.

What to Do

1. Fold the graph paper along one of the lines. Place the folded edge of the paper across the topographic representation of Orr Mountain. The folded edge should be down, running east to west, and passing through the Lookout on the mountaintop. The southern half of the mountain should be visible.
2. Reading across the folded edge, determine the lowest elevation that the folded edge passes through at the bottom of the mountain. (The lowest elevation can be on either side of the mountain. Also, because the base lines are irregular, you can use the lowest numbered contour line as your starting point.)
3. Record the lowest elevation in the margin of your paper. Also record the highest elevation (the mountaintop) that the folded edge passes through.
4. In ascending order, number horizontal lines to match the numbered intervals used on the map (200 feet). Number the line on the folded edge with the lowest numbered elevation. Number a line above the folded edge to match the next elevation, in ascending order (4600, 4800, etc.) until you reach 6000 (the next interval above the peak).



5. Along the folded edge, make a check mark at each location where the folded edge crosses a numbered, darker contour line. Next to the check mark, record the elevation.
6. Directly above each check mark, draw a dot on the line with the same elevation. Connect the dots with a smooth curve.

Questions

1. How does the profile you drew compare with those drawn by others in the class? Are they all more or less similar in outline?
2. How could you make your profile more closely represent the cone of the topographic map?

Conclusion

From the shape of your outline, would you say that Orr Mountain is a shield cone, a cinder cone, or a composite cone?

Section 1 Review Chapter 10

Check Your Vocabulary

caldera
cinder cone
Circum-Pacific Ring of Fire
composite cone
fissure
fumarole
island arc
lateral eruption
lava
magma
mid-ocean ridge
plateau basalts
shield cone
vent
viscosity
volcanic activity
volcano

Match each term above with the numbered phrase that best describes it.

1. A large circular depression that forms when a volcanic mountaintop collapses into the magma chamber beneath the mountain
2. An eruption from the side of a volcano
3. Any earth process by which molten rock, gases, or fragments of solid material come out of an opening (called a vent) in the earth's crust
4. An opening in the earth's crust from which volcanic materials pass to the earth's surface
5. A vent or mountain from which volcanic materials pass to the earth's surface
6. A volcanic vent or opening that gases and smoke come out of
7. A measure of how easily a liquid flows
8. Molten rock below the surface of the earth
9. Molten rock on the surface of the earth
10. A volcanic mountain with gently sloping sides; built almost entirely of lava flow
11. A small volcanic mountain with steep sides
12. A mountain built of alternate layers of lava flows and volcanic cinders and ashes
13. A long crack from which lava flows
14. Thick buildups of horizontal layers of basalt on continents that form as a result of lava flows from fissures
15. The entire group of volcanoes located around the Pacific Ocean
16. A curve-shaped group of volcanic islands
17. A system of tall, rugged, submerged mountains that form the single most dominant feature of the ocean bottoms

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. $\underline{?}$ is not a source of heat for volcanic activities.
   a) Internal friction in the earth
   b) Radioactive decay in rocks and minerals
   c) Underground burning of coal
   d) Leftover heat from the earth's formation
2. A magma and lava with high water content will contribute to $\underline{?}$.
   a) the building of a larger volcanic mountain
   b) an increase in explosive activity
   c) a less viscous lava
   d) a compositional change in the crustal rock that forms

Check Your Understanding

1. Explain how different volcanic activities can be destructive.
2. Describe the differences among each of the three types of volcanic mountains.
3. How do plateau basalts form?
4. Describe the three factors that determine the violence of a volcanic eruption.
5. Where are volcanic activities most commonly found on the earth's surface?

Stress, Structure, and Earthquakes Section 2

Section 2 of Chapter 10 is divided into four parts:

Rocks under stress

Movement along a fault

What is an earthquake?

Earthquake damage

Figure 10-10. This area of the Zagros Mountains, Iran, shows evidence of folding, erosion, and lava flow. What causes folded mountains to form?

The rocks that make up the earth's crust are under great pressure or stress. Sometimes, this stress causes observable movement. Volcanic activity, for example, is caused by tremendous pressure and heat within the earth's crust. Earthquakes, where sections of the earth's crust can be felt or seen to move, are caused by the release of stress within the earth's crust.

Sometimes, however, stress and movement within the earth's crust can only be inferred. By studying certain changes in the earth's crust, it is possible to infer the causes of those changes.

Rocks under stress

When you apply pressure to a piece of wood, one of several things will happen. 1) If the piece of wood is thick and strong, there will probably be no noticeable change in the wood. 2) If the piece of wood is thin like a ruler and the pressure is not too great, the piece of wood will bend. 3) If you keep putting more pressure on the ruler, the piece of wood will bend only so far, and then it will break.

Rocks, too, respond to stress and pressure in a number of ways. Rocks buried deep in the earth's crust experience strong confining pressure and heat. Forces within the earth cause stresses to build up in the rocks. As the stresses get stronger, the rock will change. Rock can change in volume, in shape, or in both volume and shape. Figure 10-11 shows simple changes in volume and shape.

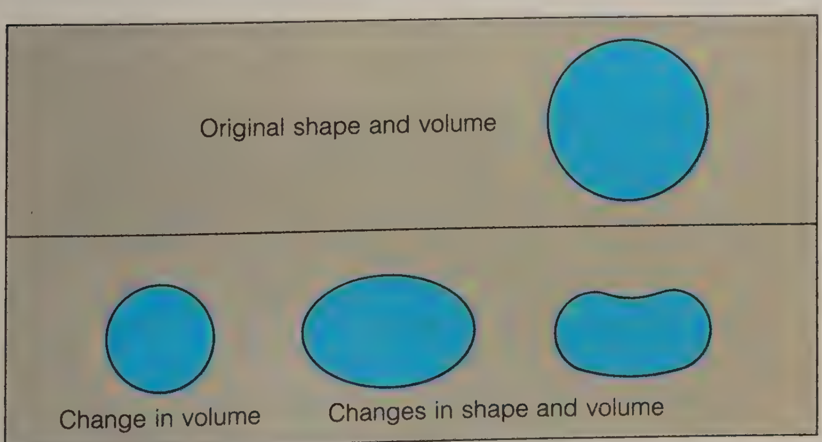


Figure 10-11. Stresses can cause rocks to change in shape or volume or both.

Library research

Find photographs of landforms that are clear examples of folded rock structures.

The volume of a rock can be changed by the elimination of pore spaces when the mineral grains in the rock are forced closer together. Under extreme pressure and heat, atoms in the minerals will rearrange themselves into new and denser minerals. This is the kind of change that takes place when metamorphic rock is formed.

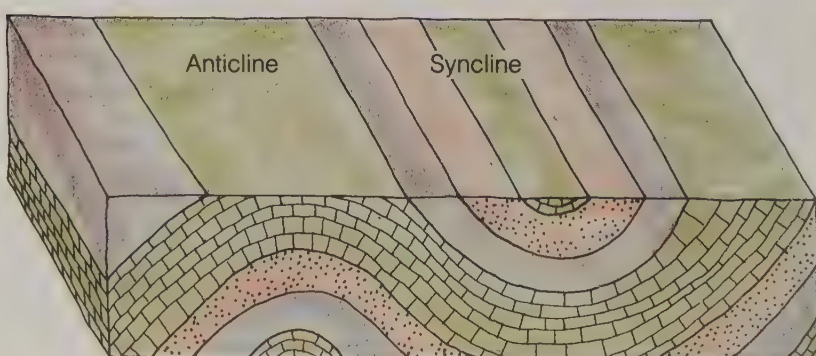
The shape of a rock can be changed when stresses are put on rocks under high confining pressures. When this happens, many of the rocks will bend, flow, and deform like modeling clay. Geologists call this type of change in rocks **plastic deformation.**

Rocks that have been bent by high confining pressure are called **folded rocks.** The two most common types of folds in rocks are synclines (SIN′-klīnz) and anticlines (AN′-ti-klīnz). Figure 10-12 shows a block diagram of rock layers that have been folded into a syncline and an anticline. A **syncline** is a downward-arching fold in rocks. An **anticline** is an upward-arching fold in rocks.

The layers of an anticline slope downward and away from the highest point of the fold in the same way that the sides of a sloped roof slant away from the ridge that runs along the top of the roof. The layers of a syncline, on the other hand, slope downward and inward towards the lowest point of the fold.

Synclines and anticlines extend lengthwise and vary in size. In width, a syncline or anticline can be anywhere from microscopic to several kilometers. In length, synclines and anticlines can extend for many kilometers. In fact, great mountain systems like the Alps in Europe and the Appalachians in North America contain synclines and anticlines.

Figure 10-12. Which is an upward-arching fold in rocks —a syncline or an anticline?



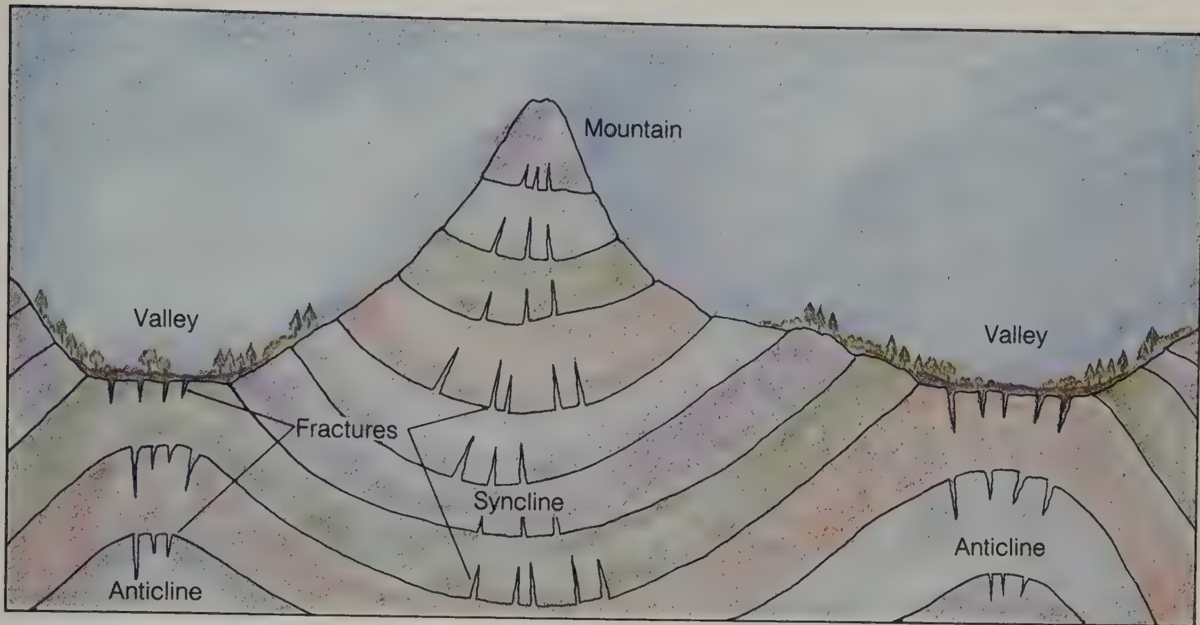


Figure 10-13. How can valleys form in anticlines?

As rocks are folded into synclines and anticlines, the rocks may develop cracks called **fractures** (FRAK′-cherz). These fractures frequently occur where the bending is the strongest—along the bottom of a syncline or the top of an anticline. These fracture zones are zones of weakness that may experience rapid weathering and erosion. Commonly, valleys develop along the tops of eroded anticlines. This is evidenced by the pattern of streams which is controlled by the underlying structure.

Figure 10-13 shows the relationship among synclines, anticlines, mountains, and valleys. As shown in the diagram, fractures along the tops of anticlines can lead to the erosion of a valley. And the erosion of the tops of anticlines on both sides of a syncline can leave the syncline elevated as a long mountain ridge.

In what part of an anticline do fractures occur?

Different kinds of stress exist within the earth's crust. Taking the ruler as an example, one kind of stress is applied when you push in on the two ends of the ruler. If the ruler is thin enough, the ruler will bend in the middle. This form of stress, in which matter is being pushed together or compressed, is called **compressional stress.** Synclines and anticlines are caused by compressional stress.

Upward and downward stresses also exist within the earth's crust. Using the ruler as an example, it is possible to apply stress to the ruler by pushing down or up on the ruler. If this kind of pressure is applied to the middle of the ruler, the ruler will bend one way or the other.

Activity Simulating Anticlines and Synclines

Materials
sheet of paper

marker pens, 2 different colors

Purpose
To study the relationship between synclines and anticlines.

What to Do
1. Working in pairs, one person cradles a sheet of paper between his or her hands (as shown in the picture) and then slowly pushes the hands together to create folds in the paper.
2. Using the two marker pens, the other person marks the tops of the folds with one color and bottoms of the folds with the other color.

Questions
1. Which folds represent anticlines?
2. Which folds represent synclines?

Conclusion
How are anticlines and synclines related? What type of force created the folds?

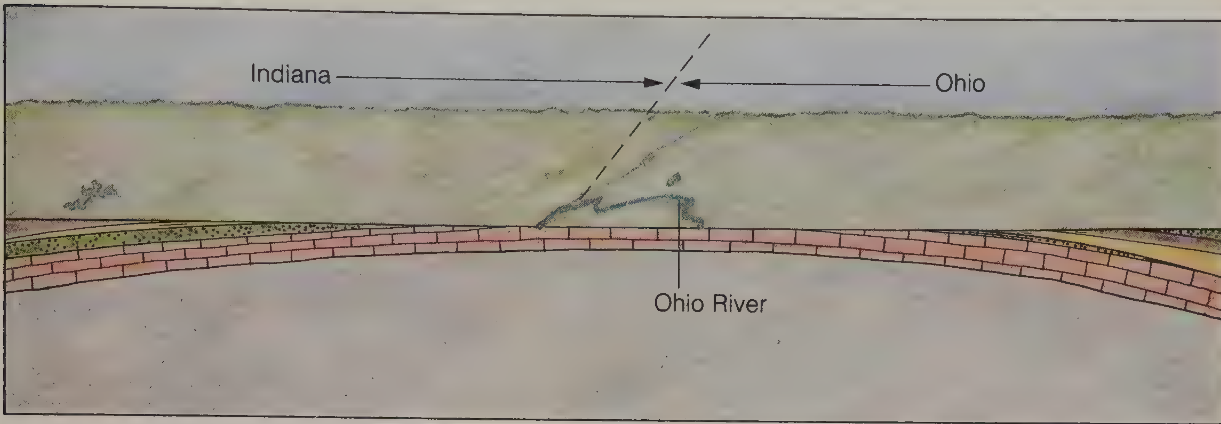


Figure 10-14. A dome (also called an arch) covers a large area of the earth's surface. The front of this diagram, an east-west cross section of the Cincinnati Arch, represents approximately 160 km.

In the earth's crust, upward and downward stresses are responsible for the formation of folded structures called domes and basins. Domes and basins are circular or oblong when seen from the air. A dome is an up-arched structure. In cross section, each of the individual rock layers of a dome would look like an upside-down bowl. The upward-pushing pressures that cause domes are sometimes associated with igneous activity.

A basin is just the opposite of a dome. A basin is a rock structure that is bent downward. In cross section, each of the individual rock layers of a basin would look like a bowl right side up. Basins are created by the sinking of the earth. As the earth sinks, more sediments pour into the basin and cause the rock layers of the basin to sink deeper. Figure 10-14 gives some idea of how large a dome can be.

Library research

Find the location of the earthquake fault closest to where you live. What kind of fault is it? When was the last time that movement took place along that fault?

Check yourself

1. What types of changes in rocks can be caused by stresses in the earth's crust?
2. What is plastic deformation?
3. What are the differences among anticlines, synclines, basins, and domes?
4. How does change in volume due to pressure create metamorphic rocks?

Movement along a fault

Rocks that fold when deep in the earth may break when put under stress nearer the surface. Breaks in rocks can be caused by compressional stress, tensional stress, or shear stress.

What kinds of stresses cause breaks in rocks near the surface?

Activity Making a Fault Model

Materials

modeling clay, three different colors

pencil

thin wire, 3/4 to 1 m long

2 small pieces of wood

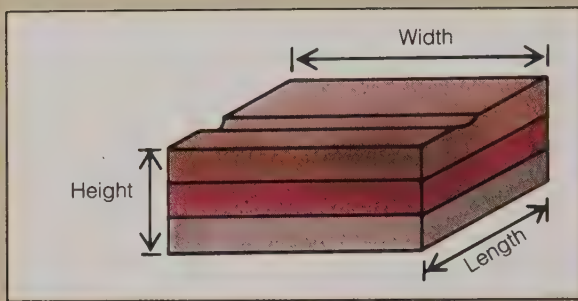
Purpose

To make a model of a geologic fault.

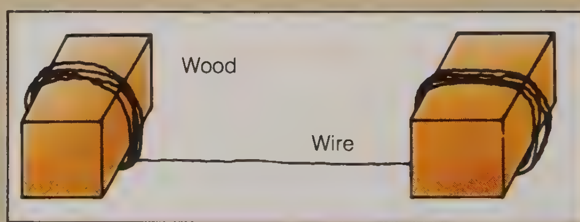
What to Do

1. To make the model, form three flat layers of modeling clay, each a different color and each about 1 cm thick. Stack the layers on top of one another.
2. Use the blocks of wood and the wire to make a cutter similar to a cheese cutter. Wrap a few turns of wire around one of the pieces of wood until it is tight and won't slip. Do the same with the other piece of wood and the other end of the wire. Leave a length of wire between the pieces of wood that is just a few centimeters longer than the width of the stacked clay layers.
3. Make a canal across the width of the top layer of clay by pressing a pencil lengthwise halfway into the top clay layer.
4. To create the fault, use the wire to cut completely through the clay layers at a 45° angle.
5. Measure and record the width and length of the block. (Note: Be sure to save your model and your measurements for use in another activity later in this section.)

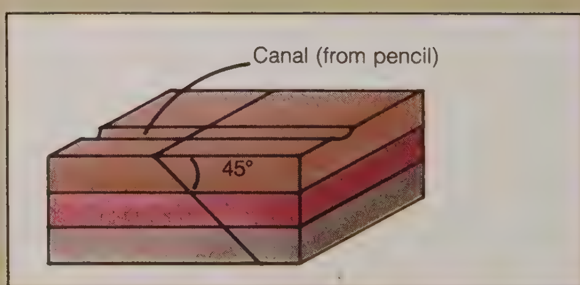
Step 1



Step 2



Step 3



Questions

1. What three kinds of stress might affect the fault model you have made?
2. Draw a cross section of your fault model and label the hanging wall and the footwall.

Conclusion

Now that you have made your model, which type of faulting would you predict would stretch your model? Which type would shorten it? (Hint: see page 493.)

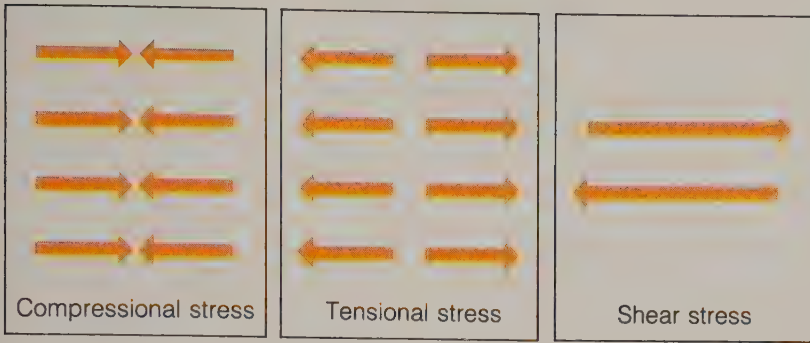


Figure 10-15. When you stretch a rubber band, are you applying compressional, tensional, or shear stress?

Stretching a rubber band is an example of applying a **tensional stress.** Rubbing your hands past one another is an example of **shear stress.** Figure 10-15 shows the directions of the forces in compressional stress, tensional stress, and shear stress.

You may have heard of faults or perhaps you have heard about a particular fault, such as the San Andreas fault that passes near the city of San Francisco, California. A **fault** is a break or fracture in rocks along which the rocks move. Compressional and tensional stresses cause an up-down movement along a fault. Shear stress causes horizontal movement along a fault.

What is a fault?

Figure 10-16 shows a cross section of a fault that is not at 90° to the surface. The rock masses on either side of such a fault are known as the hanging wall and the footwall. The **hanging wall** is the mass of rock that is above the fault. The **footwall** is the mass of rock that is below the fault. (The names are from mining. Normally, miners walk on the footwall and hang their lanterns on the hanging wall.)

Faults are classified according to the direction in which the rocks move on either side of the fault. A **normal fault,** shown in Figure 10-17, is one in which the hanging wall has moved

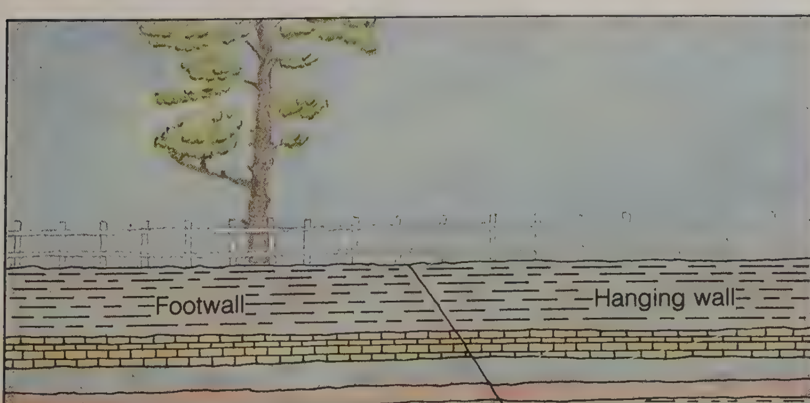


Figure 10-16. Which mass of rock is above a fault—the hanging wall or the footwall?

Activity Simulating Faults

Materials

Fault model made in previous activity, "Making a Fault Model"

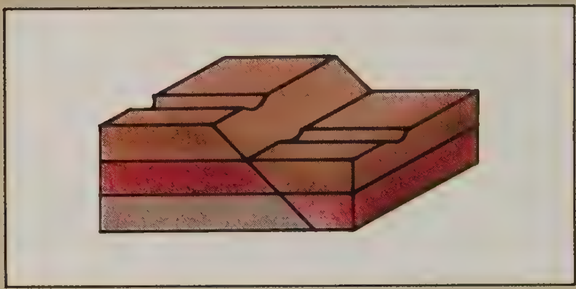
Purpose

To simulate a variety of geologic faults.

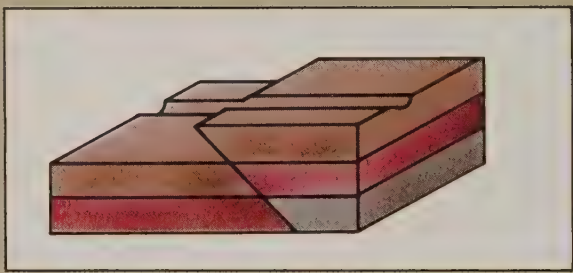
What to Do

1. From the hanging wall block of your fault model, remove the bottom layer of clay. Then put the hanging wall back against the footwall as shown in illustration A.
2. Measure and record the length and width of the clay model.
3. Next, replace the bottom clay layer you removed in step 1. From the footwall block, remove the bottom layer of clay. Then put the footwall back against the hanging wall as shown in illustration B.
4. Measure and record the length and width of the clay model.
5. Replace the bottom layer of clay removed in step 3.
6. Move the hanging wall block laterally by using a shear stress as shown in illustration C.
7. Measure and record the length and width of the clay model.

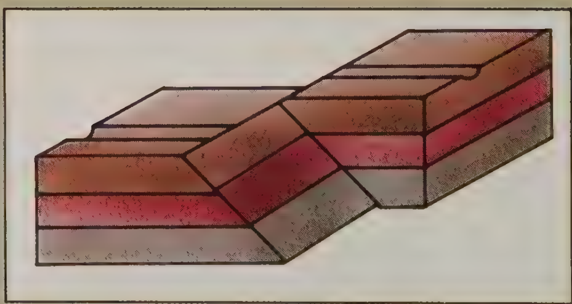
A



B



C

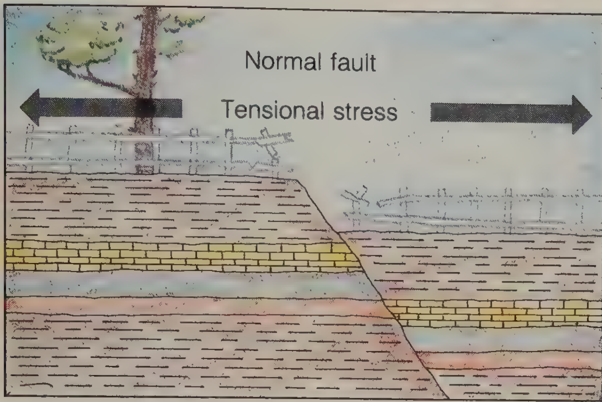


Questions

1. When you followed the directions in step 1, what type of fault did you simulate? Describe what happened to the canal.
2. When you followed the directions in step 3, what type of fault did you simulate? Again, describe what happened to the canal.
3. When you followed the directions in steps 5 and 6, what type of fault did you simulate? What happened to the canal?
4. Which type(s) of faulting offsets the canal sideways?

Conclusion

You have simulated several kinds of faults. Which type of stress (compressional or tensional) would create reverse faults? Which would create normal faults?



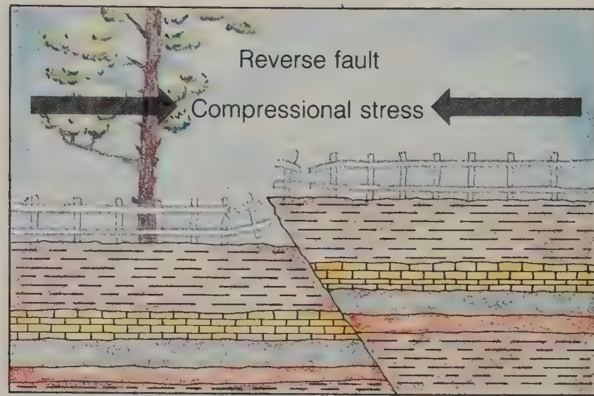


Figure 10-17 (left). A normal fault.

Figure 10-18 (right). A reverse fault.

down with respect to the footwall. In a normal fault, movement along the fault is caused by tensional stress in the crust.

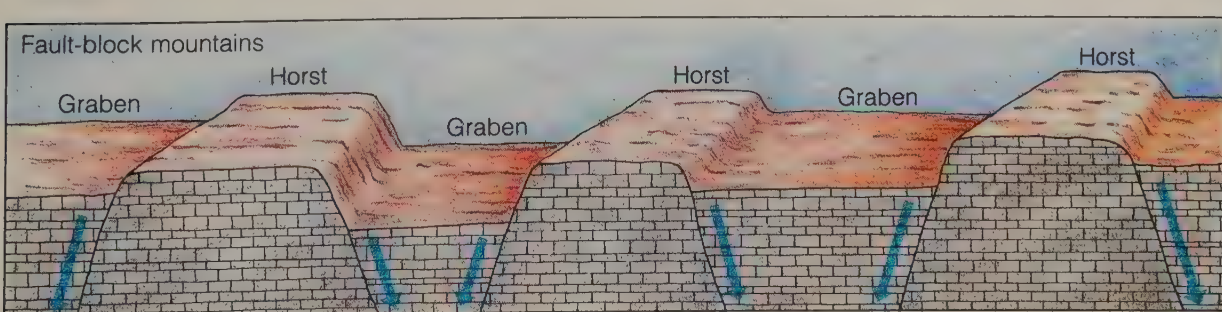
A **reverse fault,** shown in Figure 10-18, is one in which the hanging wall has moved up with respect to the footwall. In a reverse fault, movement along the fault is caused by compressional stress in the earth's crust.

A **thrust fault** is a special type of reverse fault. In a thrust fault, the fault surface is at a very low angle or even horizontal in some places. As with other reverse faults, movement along a thrust fault is caused by compressional stress.

A **transform fault** is a fault along which there is a horizontal movement similar to that when you rub your hands together. Movement along a transform fault is caused by shear stress. Most transform faults are found in the ocean crust. A few, however, extend onto the land and are rather significant. The San Andreas fault, which runs through the state of California, is an example. Along this fault, the whole western part of the state is moving northward with respect to the eastern part of the state. The great San Francisco earthquake of 1906 was caused by movement along this fault.

The up-down movement of rock masses along faults has

Figure 10-19. Fault-block mountains (horsts) form when areas of crust sink between two faults. The lowered area, called a graben (GRAH′-bin), forms a valley.



Do the Appalachian Mountains consist of folds or faults or both?

caused a variety of different kinds of landforms on the earth's surface. The Appalachian Mountains, for instance, consist not only of folds but also of numerous reverse faults and thrust faults. The Basin and Range Province of the western United States, with its fault-block mountains, is another example. And the large step-like plateaus of northern Arizona and southeastern Utah are still another example of a different kind of landform caused by the movement of rock masses along faults.

Check yourself

1. What kinds of stresses can create faults?
2. Draw a cross section of a fault, and label the hanging wall and the footwall.
3. How does the movement in a normal fault differ from that in a reverse fault?
4. What type of fault is the San Andreas fault?

What is an earthquake?

An **earthquake** is a motion, trembling, or vibration of the ground. An earthquake is caused by the release of stress that has been slowly building up in the earth's crust. An earthquake can be caused by sudden movement along a fault. An earthquake can also be caused by volcanic activity.

When an earthquake occurs, stress energy that has been building up in the earth's crust changes to wave energy. Earthquakes originate in the earth's crust or upper mantle. The point of origin of an earthquake, where stress energy changes to wave energy, is called the **focus** of the earthquake. The focus is the center of an earthquake. From this center or focus, waves spread out through the earth in all directions.

Most earthquakes occur at a shallow depth, somewhere between the earth's surface and 70 km depth. These earthquakes are said to have a shallow focus. Some earthquakes have an intermediate focus, between 70 km and 300 km depth. Only a very few earthquakes have a deep focus, between 300 km and 700 km depth.

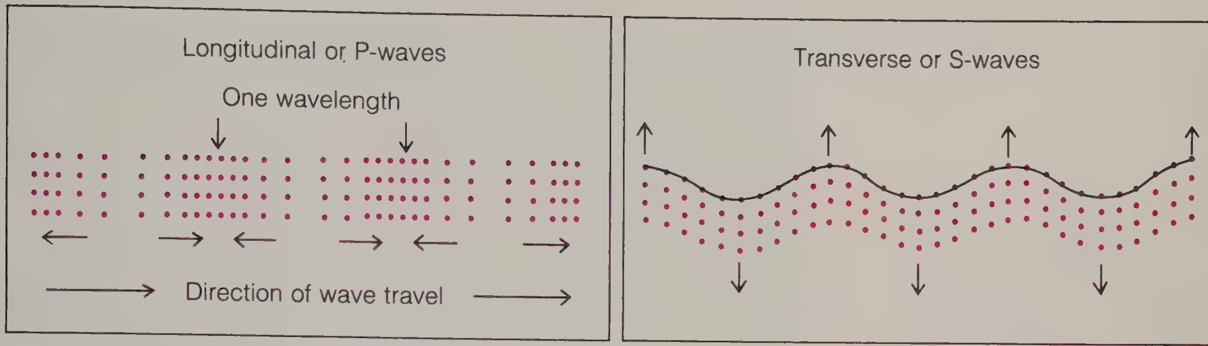


Figure 10-20. In a P-wave, the particle motions are in the same direction that the wave is traveling. How does this compare with the particle motions in an S-wave?

Earthquake vibrations produce two major kinds of waves, P-waves and S-waves. **P-waves** are primary waves. A primary wave is a longitudinal wave. In a longitudinal wave, the particles of material through which the wave is traveling move in the same direction that the wave is traveling. A longitudinal wave is also called a compressional wave because the wave compresses and then stretches the particles of material in the same direction that the wave is moving. (See Figure 10-20.)

S-waves, or secondary waves, are transverse waves. In a transverse wave, the particle motion is perpendicular to the direction in which the wave is moving. The motion is similar to a guitar string, which is set in motion by being plucked in a direction that is perpendicular to the string. Adjacent points in the direction of transverse or S-wave motion move sideways to one another as the wave passes. This motion is called shear, and S-waves are sometimes called shear waves.

What kind of wave motion occurs when you pluck a guitar string?

Both S-waves and P-waves move outward from the focus. But an S-wave causes the ground to vibrate sideways or perpendicular to the direction in which the wave is traveling. A P-wave compresses and then stretches the ground in the same direction that the wave is traveling. When P-waves and S-waves reach the surface of the earth, surface waves are set in motion. One type of surface wave is an *L-wave*. L-waves cause broad up-and-down motion that may open and close cracks in the earth.

Earthquake waves are recorded on instruments called **seismographs** (SĪZ′-muh-grafs). Many seismograph stations are located around the world. Shock waves from an earthquake arrive at different stations at different times, depending on how far away the station is from the focus. By comparing the arrival times recorded by seismographs at three or more different stations, the exact position of the focus of an earthquake can be determined. The earthquake's **epicenter,** which is the point or area on the earth's surface directly above the focus, can also be determined. (See Figure 10-21.)

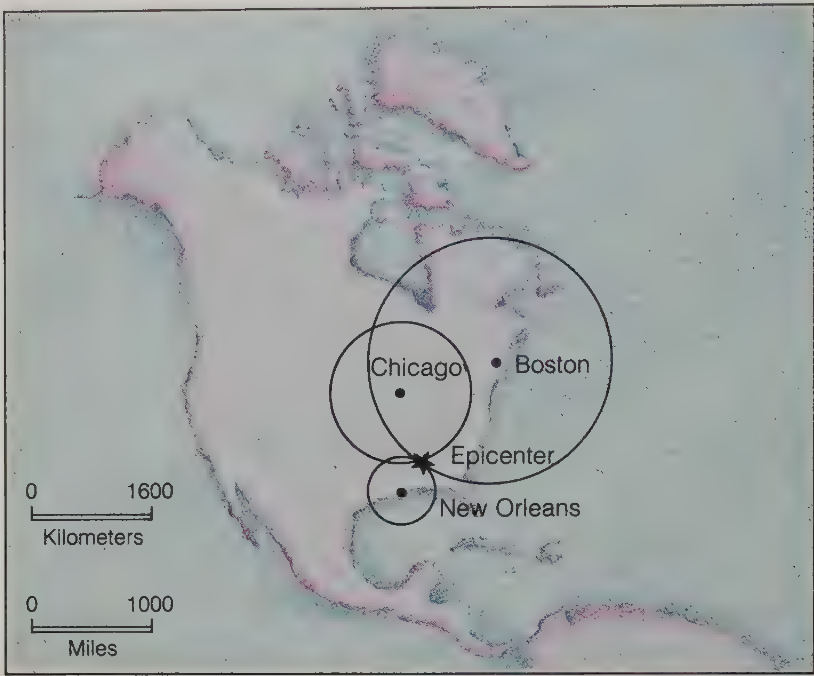


Figure 10-21. By comparing the arrival times recorded by seismographs at three or more different stations, the exact position of the focus of an earthquake can be determined. What is the relationship between the focus and the epicenter of an earthquake?

What two kinds of information are provided by a seismograph?

In addition to the arrival time of a wave, a seismograph also shows the amount of energy in the wave. From this record, the amount of energy released at the time of the movement in the earth can be calculated. The units used to measure the strength of an earthquake are based on a system devised in 1935 by Charles Richter, an American **seismologist** (a scientist who studies earthquakes). This system, known as the **Richter scale,** uses a numerical scale from 1 to 10 to measure the amount of energy released at the focus. Each of the numerical steps in the Richter scale represents a ten-fold increase in the amount of energy released. For example, a reading of 3 on the Richter scale indicates the release of 10 times more energy than would be indicated by a reading of 2 on the Richter scale. And a reading of 7.5 on the Richter scale indicates the release of 1000 (10 times 10 times 10) times more energy than would be indicated by a reading of 4.5.

Check yourself

1. What natural earth processes can cause earthquakes?
2. How is the energy in an earthquake measured?
3. What are the two major kinds of waves an earthquake produces?
4. What is the depth range of intermediate focus earthquakes?

Earthquake damage

Scientists estimate that the earth produces, on the average, an earthquake every 32 seconds. Many of these are so weak that they cannot even be felt. Others, however, do great damage. During some earthquakes, the movement of the earth's crust causes buildings and bridges to crack and collapse. Roadways are split. Landslides are set in motion and cliffs tumble into the sea.

The Richter scale measures the energy contained in a wave. It does not indicate the amount of damage that has been done. Another type of scale, the **Mercalli scale**, is used to show damage. Table 10-1 shows six of the twelve steps in the Mercalli scale, which was created in 1902 by Giuseppe Mercalli, an Italian seismologist. The Mercalli scale is still widely used to describe the amount of damage caused by an earthquake.

Figure 10-22. On Thursday, September 19, 1985, Mexico City was heavily damaged by an earthquake. With a force of 8.2 on the Richter Scale, the shock waves were felt as far away as Houston, Texas.

Table 10-1. At what step on the Mercalli scale do cracks form in the ground?

Some Steps in the Mercalli Scale of Earthquake Damage	
Step	Extent of Earthquake Damage
I	The earthquake is felt by only a few people near the epicenter.
III	The earthquake is felt in buildings, but usually only on the upper levels.
V	Windows and fragile objects are broken.
VII	People run out of buildings, and some masonry breaks.
IX	Cracks form in the ground, and all buildings are damaged.
XII	Objects are thrown into the air, and all structures are destroyed.

The amount of damage caused by an earthquake depends on several factors.

1. The amount of damage depends in part on the amount of energy in the earthquake waves.
   a. Usually the damage is greatest at the epicenter and becomes less severe as the earthquake waves get farther away from the epicenter.
   b. In areas where fault movement is fairly frequent, earthquakes are usually not strong enough to cause severe damage. But in areas where the movement along a fault is rare, stresses in the earth may build up to such a strength that, when the earth does slip, a great amount of energy is released and can cause heavy damage.
2. The amount of damage depends on the type of rock or sediment through which the earthquake waves are moving. Soft sediment will allow more damage than a solid bedrock such as granite. That is why buildings constructed on loose sediment 100 km from an epicenter may experience more damage than buildings built on granite at the site of the epicenter.
3. The amount of damage depends on the type of building materials and the type of construction used in the area that is experiencing the earthquake. (Wood frame buildings, for example, may suffer less damage than buildings made of materials that are cemented together.) In an earthquake, some flexibility within the individual structures is desirable.

In some cases, the earthquake-caused breaking of water and sewer pipes is a greater threat to a community than is the initial shock damage. During the great San Francisco earthquake in

Library research

Provide data for five earthquakes that occurred within the last ten years. For each, give the date, location, intensity according to the Richter scale, brief description of the earthquake damage, and the source of your information.

1906, most of the damage was caused by fires that could not be put out because the water pipes had all been broken. And the health hazard due to unsafe water and disrupted sewage lines often causes greater loss of life than falling buildings.

When and where did the most deadly earthquake in history occur?

The most deadly earthquake in history, killing 830 000 people, occurred on January 24, 1556, in Shenshi Province, China. China also experienced disastrous earthquakes on December 16, 1920, and July 28, 1976.

Earthquakes are common along active fault zones. And certain types of earthquakes are associated with volcanic activity. In an area of volcanic activity, for example, many shallow-focus earthquakes immediately precede an eruption. These particular earth movements are probably caused by the movement of magma just beneath the surface of the earth. Knowing that earthquakes are associated with fault zones and with volcanic activity, engineers and scientists can predict in a general way where earthquakes are most likely to occur on a regular basis. In some cases, the amount of energy that might be released can also be predicted. With this kind of information, construction sites and building codes can be designed that will give maximum safety to people living in earthquake areas.

What caused the Mississippi River to flow in the opposite direction?

Some very destructive earthquakes occur in places where they are least expected. In 1811 and 1812, the interior of the United States was rocked by a series of earthquakes that were centered near New Madrid, Missouri. (These earthquakes rocked the Mississippi Valley so violently that for a short time the Mississippi River flowed north!) And in 1866 the epicenter of a severe earthquake was located near Charleston, South Carolina. For people living in areas like these, which are outside the obvious earthquake zones, it is difficult to prepare for an earthquake because several generations may pass between one earthquake and the next.

Check yourself

1. How is the amount of damage done by an earthquake related to the amount of energy?
2. Besides energy, what other factors affect the amount of damage done by an earthquake?
3. What is the Mercalli scale?

Section 2 Review Chapter 10

Check Your Vocabulary

anticline
compressional stress
earthquake
epicenter
fault
focus
folded rock
footwall
fracture
hanging wall
Mercalli scale
normal fault
plastic deformation
P-wave
reverse fault
Richter scale
seismograph
seismologist
shear stress
S-wave
syncline
tensional stress
thrust fault
transform fault

Match each term above with the numbered phrase that best describes it.

1. A special type of reverse fault
2. A fault with horizontal movement
3. A fault in which the hanging wall has moved down with respect to the footwall
4. A fault in which the hanging wall has moved up with respect to the footwall
5. The mass of rock that is above a fault
6. The mass of rock that is below a fault
7. Stress when matter is pushed together
8. A fracture along which rocks move
9. A downward-arching fold in rocks
10. An upward-arching fold in rocks
11. A crack in folded rocks
12. Rock bent by high confining pressure
13. When rocks deform like modeling clay
14. Stress when material is pulled apart
15. Stress when rocks slide past each other
16. A scientist who studies earthquakes
17. A system that measures the amount of energy released at the focus of an earthquake
18. Describes the amount of earthquake damage
19. A secondary wave
20. Measures and records earthquake waves
21. The point directly above the focus
22. A motion or trembling of the earth
23. The point of origin of an earthquake
24. A primary wave

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. Shear stress can be represented by these arrows: ?.
   a) ⟶ ⟵ c) ⟶ ⟶
   b) ⟵ ⟶ d) ⟶ over ⟵
2. In terms of earthquake protection, it is best to construct a building on ?.
   a) loose sand c) clay
   b) granite d) hard-packed sand

Check Your Understanding

1. How can the location and strength of an earthquake be determined?
2. How can folded rocks affect weathering and erosion?
3. Draw and label a normal fault and a reverse fault. Use arrows to show the directions of movement of the hanging wall in relation to the footwall.
4. How are tensional and compressional stresses related to faulting and folding?
5. Describe and give examples of how faults and folds are related to different landforms.

Plate Tectonics Section 3

Section 3 of Chapter 10 is divided into four parts:

The interior of the earth

The theory of continental drift

The theory of plate tectonics

Pangaea

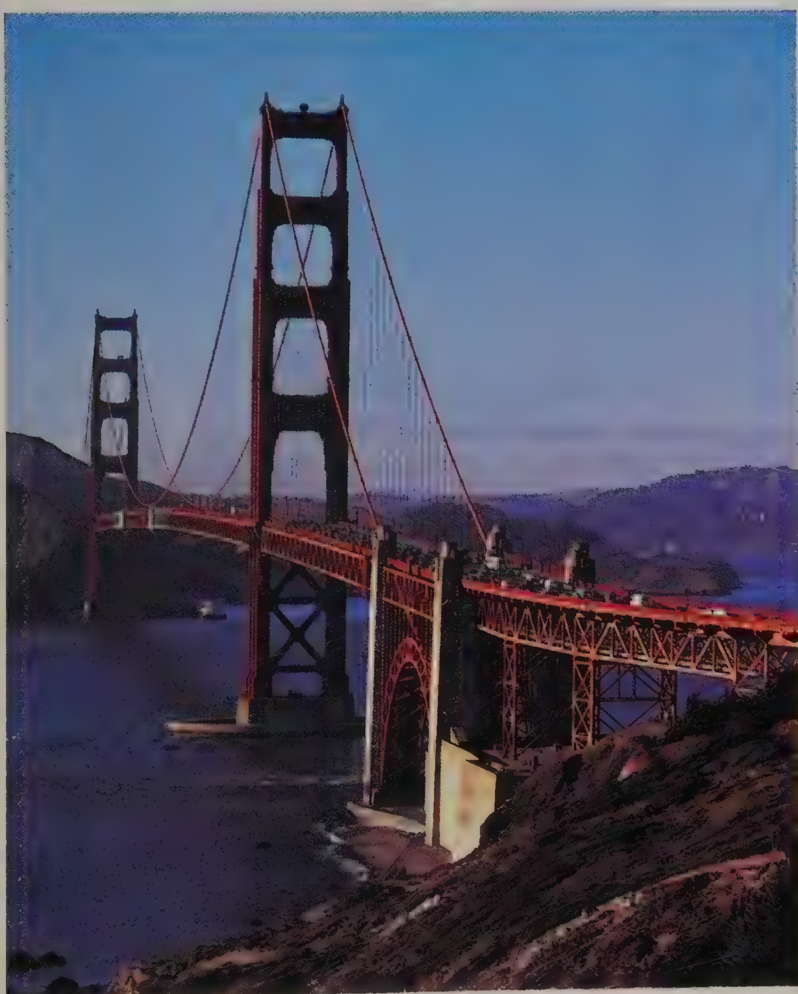


Figure 10-23. The Golden Gate Bridge (San Francisco, California) could never have been built if it weren't anchored into "solid earth." Just how solid is the earth?

What two kinds of people would especially appreciate setting foot on solid earth again?

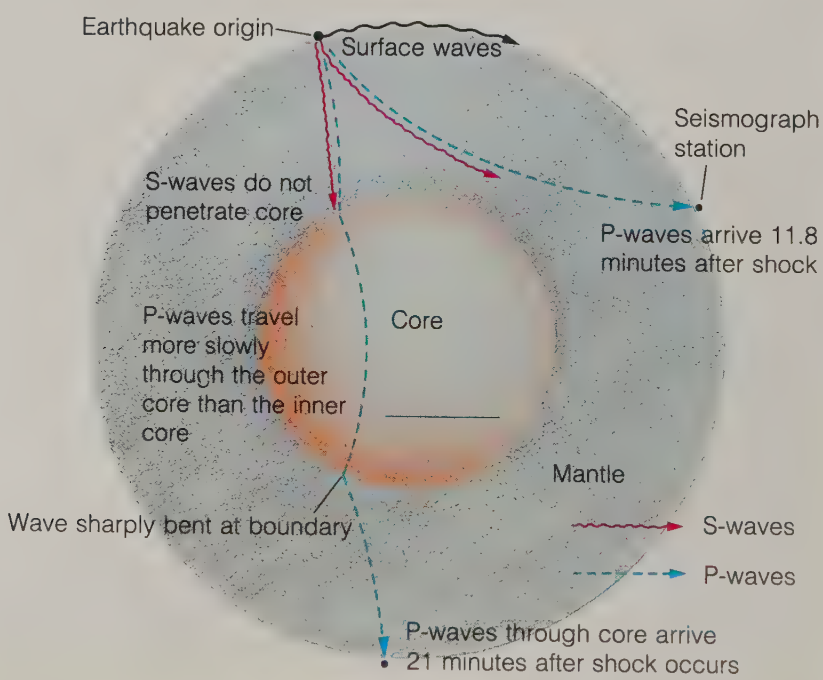
Imagine what it must be like for an astronaut to return to the earth after walking on the moon and being in space for eight days or more. Or imagine how it would feel to reach land safely after surviving a storm at sea. How good it would feel to set foot again on solid earth!

The solid earth is a term frequently used to describe the land, especially landmasses that are as large as continents. In this section of Chapter 10, you will learn more about just how solid the earth really is. You will also learn about a theory that explains volcanic activity and earthquakes and the formation of some of the most spectacular landforms on the earth.

The interior of the earth

Properties of earthquake waves have enabled scientists to learn much about the earth's interior. P-waves will travel through both solid and liquid, although P-waves slow down when they pass through a liquid. S-waves will travel through a solid but not through a liquid. And both types of waves slow down when they approach a material that has the consistency of putty.

Figure 10-24. How have scientists determined that the outer part of the earth's core behaves as a liquid?



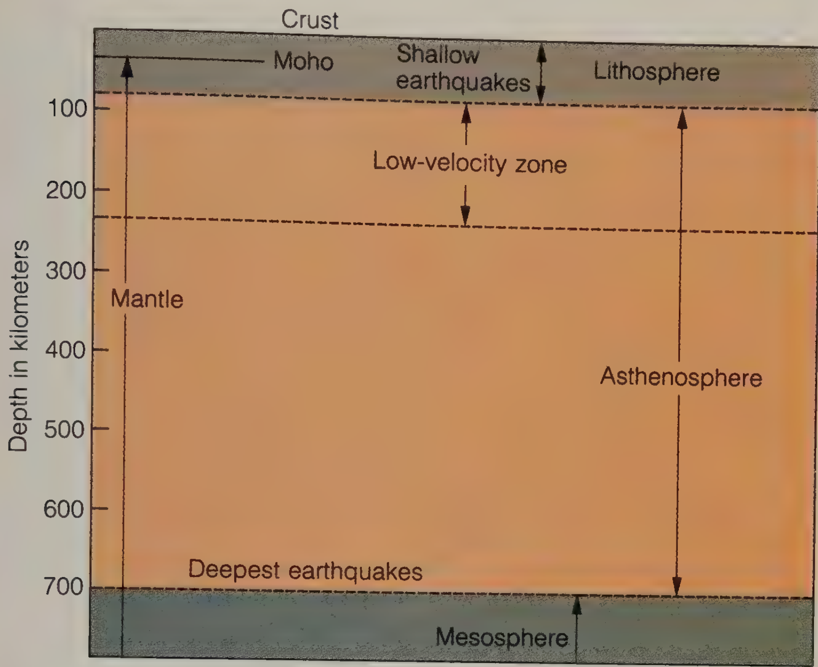


Figure 10-25. Why is the low-velocity zone called by that name?

By studying the arrival times of P-waves and S-waves, scientists have been able to determine that the earth consists of different layers. These layers are called the crust, the mantle, and the core. Scientists have also determined that the outer part of the core behaves as a liquid because it blocks out S-waves. The inner core behaves as a solid, which scientists can determine because of the change in speed by P-waves traveling through the liquid outer core and then through the inner core.

By studying earthquake waves, scientists have discovered another zone within the upper mantle. This zone has the ability to slow down both P-waves and S-waves and is called the **low-velocity zone.** The low-velocity zone is where intermediate focus earthquakes originate.

By studying the arrival times of earthquake waves, scientists have also determined that the densities of the materials in the different layers in the earth increase toward the core.

The divisions of crust, mantle, and core within the earth are based on earthquake wave velocities. Boundaries between these divisions show sharp changes in earthquake wave velocity. These boundaries between the divisions of the earth's interior are called **discontinuities.**

The earth's crust is mostly made of two basically different types of materials, basalt and granite. **Oceanic crust** is basaltic, denser than continental crust, and about 5 km thick. **Continental crust** is granitic and varies in thickness between 20 and 60

Library research

What is the Mohorovicic discontinuity (Moho for short)? How did it get its name?

What have scientists learned about the densities of the earth's layers?

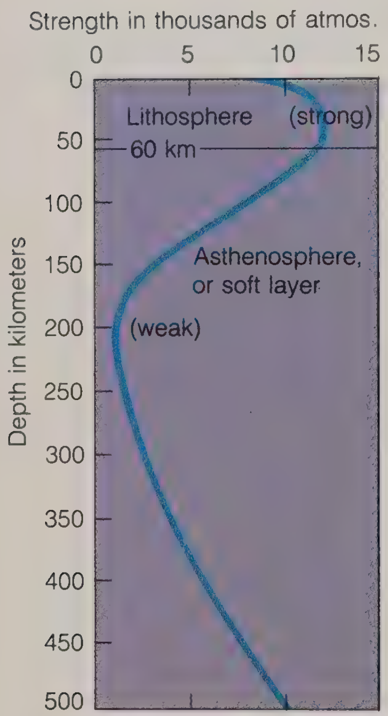


Figure 10-26. This diagram gives a rough estimate of the rigidity of rock in the earth's lithosphere and asthenosphere. In which layer is the rock most rigid?

km. The lower part of the granitic crust rests on crustal material similar to oceanic crust.

A different division of the earth into layers can be based on the strength and rigidity of the rocks. **Rigidity** is a measure of stiffness. Using this method of division, layers in the earth are the lithosphere (LITH′-uh-sfir), the asthenosphere (as-THEN′-uh-sfir), the mesosphere (MES′-uh-sfir or MEZ′-uh-sfir), and the same core as in the other set of divisions. The **lithosphere** includes all of the crust plus part of the upper mantle and is thin compared to the surface area of the earth. The **asthenosphere** and **mesosphere** correspond to the rest of the mantle below the lithosphere. The lithosphere is relatively cool and rigid. (See Figure 10-26.) The asthenosphere is hot and relatively soft. The mesosphere is in between the asthenosphere and lithosphere in terms of rigidity but is very hot and under very high pressure.

Check yourself

1. What are the boundaries between the core, mantle, and crust?
2. What gives the low-velocity zone its name?
3. Name the earth's layers, as based on strength and rigidity.

The theory of continental drift

In 1620, the Englishman Francis Bacon noted that the shape of the coastlines on both sides of the Atlantic Ocean was such that the continents could fit together like a jigsaw puzzle and that the continents had possibly drifted apart. During the nineteenth century, several observations seemed to support the concept that the continents had drifted apart.

1. Rocks on opposite sides of the Atlantic Ocean were of similar types, ages, and sequences of layers in those areas that would meet if the continents were pushed together.

2. Included in some of those rocks were plant and animal fossils. Their distribution pattern was most logically explained on the basis that all the continents had been together at one time.

How did plant and animal fossils influence the theory of drifting continents?

Figure 10-27. What did Francis Bacon, in the year 1620, note about the shape of the Atlantic coastlines?

3. Another type of evidence was that certain mountains and faults lined up if the continents were pushed together.

Any of these observations standing alone was not sufficient evidence to prove that the continents had been together at one time. In a court of law, when several pieces of circumstantial evidence all point to the same conclusion, the case becomes much stronger. Statistically, this is also true for scientific observations. The cumulative evidence for drifting continents was quite strong.

How strong was the cumulative evidence in support of drifting continents?

Many different evidences for continental drift were first brought together in 1915 in a book written by Alfred Wegener, a German geologist, meteorologist, and explorer. The title in English of Wegener's book is *The Origin of Continents and Oceans.* In that book, Wegener, who is credited with being the founder of the **theory of continental drift,** envisioned the continents drifting over the top of the oceanic crust.

Other scientists, however, considered the theory of continental drift to be impractical or even impossible. No known forces were strong enough to overcome the friction between the two crustal rock types. In 1931, an English geologist by the name of Arthur Holmes speculated that continental drift might be

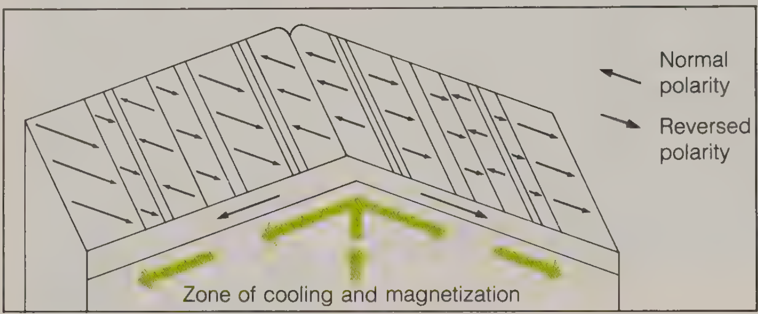
Library research

Find out more about sea floor sediments. How are they important to our understanding of the plate tectonic theory?

Our Science Heritage

From Hypothesis to Theory

In the early 1960s, some puzzling variations in magnetic patterns above the ocean bottom were observed. In 1963, a pair of British scientists, F. J. Vine and D. H. Matthews, proposed the following solutions to these patterns.



First of all, they suggested that the crustal rock under the oceans was formed from a molten basaltic material from the earth's mantle. As the molten basalt cools, it becomes permanently magnetized in the direction of the prevailing magnetic forces that are associated with the North and South Magnetic Poles.

Secondly, Vine and Matthews suggested that the earth's magnetic field reversed in direction several times during earth history. They hypothesized that the magnetic reversals would explain the north-south bands of magnetic variations observed above the floor of the northeast Pacific Ocean.

By 1966, ocean crust age dates verified the concept of magnetic reversals and suggested a pattern of reversals for the preceding three and a half million years (during which time the earth appears to have reversed polarity at least nine times).

The working hypothesis that Vine and Matthews had proposed as a way to explain certain observations led to a more detailed understanding of the ocean bottom. This in turn led to further discoveries and played an important part in the development of the plate tectonic theory.

caused by convection currents beneath the earth's crust and that the oceanic crust was acting like a slowly-moving conveyor belt. But because of lack of evidence, Holmes's idea did little to make the theory more acceptable to other scientists.

During the 1940s, scientists studying the ocean bottom learned many new things about the ocean crust. Then, in 1961 and 1962, Harry Hess and Robert Dietz proposed a theory of sea floor spreading similar to that of Holmes, but Hess and Dietz had more supporting evidence. In addition, Hess and

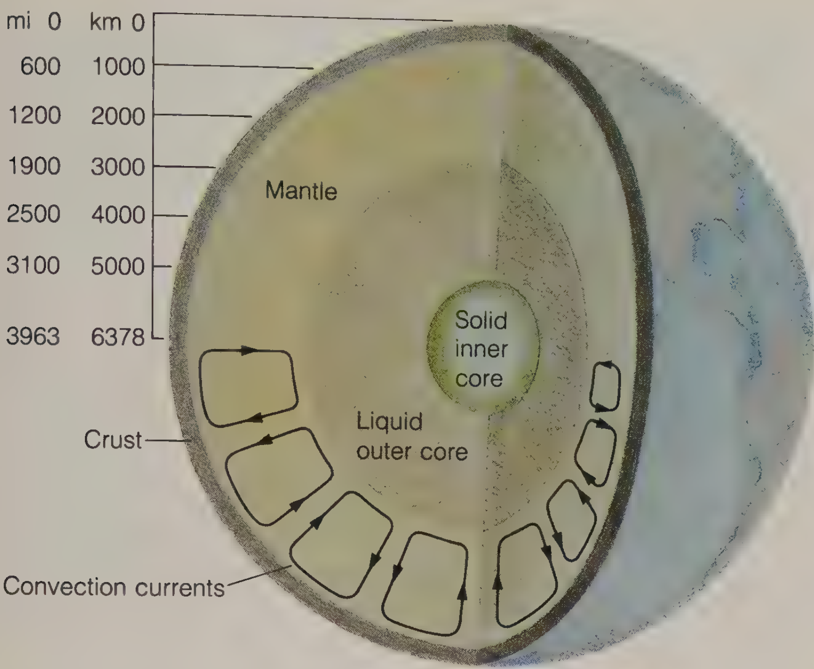


Figure 10-28. What did Arthur Holmes offer, in 1931, as a possible explanation for continental drift?

Dietz expanded the theory to include the destruction of ocean floor material where ocean crust meets continental crust.

In 1965, with the addition of magnetic studies of the ocean's crust, J. Tuzo Wilson consolidated the concept of sea floor spreading and the theory of continental drift into the theory of plate tectonics. Wilson described the basic nature of plates and plate boundaries.

How did Hess and Dietz expand Holmes's theory of sea floor spreading?

One of the lessons that can be learned from this sequence of events is that "impossible theories" may be very important in the development of scientific concepts. The theory of continental drift produced vigorous debate during Wegener's time. Even though other scientists clearly showed that the theory was impossible, the impossible theory stimulated thought, led to more data gathering, and continued to be a focal point of debate. And the result was well worth the effort. All this data gathering and debate finally led to a new synthesis, a synthesis considered by many scientists to be the great unifying theory of geology. This great unifying theory is known as the theory of plate tectonics.

Check yourself

1. In which century was the idea of continental drift first mentioned?
2. What was Wegener's contribution to the idea of continental drift?

3. What types of information from the 1940s through the 1960s led to the sea floor spreading theory and the theory of plate tectonics?

The theory of plate tectonics

The plate tectonic theory, which was first described in 1965, is a relatively recent scientific theory. Roots of the theory, however, extend back into the seventeenth century. The **plate tectonic theory** states that the surface of the earth consists of several lithospheric plates of rock. According to the theory, the plates are rigid and moving very slowly. Where different plates meet each other, one of three things happens. The plates grow larger, the plates collide, or the plates move past each other with a shearing motion.

How do crustal plates grow?

Plates grow by the addition of molten material along great faults. This is what happens along the mid-ocean ridge.The central part of the mid-ocean ridge, which is called a **rift zone,** is a zone of tensional stress. Huge sections of the sea floor are being pushed or pulled in opposite directions. To fill the gap in the ocean crust, molten material rises from deep in the earth and cools into igneous rock. Tensional stress eventually causes a fault to form in this new rock and the process is repeated. This faulting and movement of growing plates away from a central rift zone (plates can move up to 9 cm per year) is what is known as **sea floor spreading.**

What happens when crustal plates collide head-on?

When plates collide head-on, one of two results is possible. One possibility is that the edges of the plates, or the plate margins, can buckle up and form mountains. Another possibility is that one of the plate margins can be forced downward into the asthenosphere. This type of downward movement is called **subduction.**

Subduction of oceanic plates causes the formation of deep ocean trenches. A subducting plate is destroyed by the time it reaches the mesosphere. Rock in the subducting edge will eventually be recycled back to the surface, either through extremely slow convection motion of hot rock within the asthenosphere or by magma pushing up to form volcanoes. This magma pushing up to form volcanoes is the source of the vol-

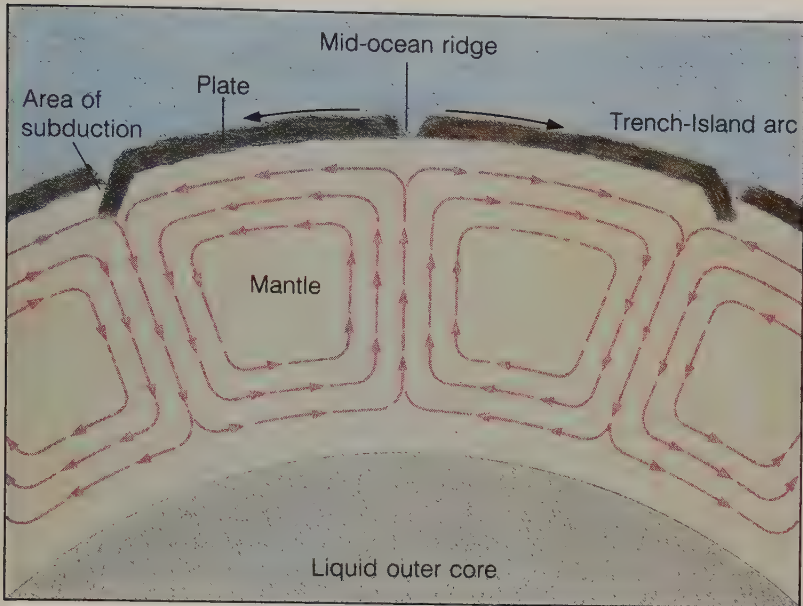


Figure 10-29. In sea-floor spreading, lithospheric plates fault, grow, and move away from a central rift zone. Eventually the plates can be forced downward into the asthenosphere. What is this type of downward movement called?

canism along the mid-ocean ridge and near the deep sea trenches.

The rigidity of the lithospheric plates allows them to carry sediments and rock that are on top of them. Therefore, the continents are carried along as part of the moving plates. Also, because of the rigidity of the plates, great fractures are developed across the mid-ocean ridge. These fractures may extend for hundreds of kilometers across the oceanic crust. When the ridge and rift zone are offset along these fractures, a transform fault develops between the offset rift zones, and the rocks on opposite sides of the fault grind past each other as the plates move. In some places, the transform fault may be a few hundred kilometers long and form margins or boundaries between plates. The Cayman Trough in the Caribbean Sea and its extension into Central America as the Montagua fault in Guatemala is an example.

Seven major plates and several smaller plates make up the earth's surface. Figure 10-30 shows the location of the plates with their boundaries. The arrows indicate directions of movement. Plate boundaries are zones where earthquake and volcanic activity are concentrated.

Much evidence supports the plate tectonic theory. Here are some of the most recent evidences:

1. Direct observation has been made of oceanic crust being formed through volcanic activity along the central rift zone of the mid-ocean ridge.

Library research

Find a map that shows fractures in oceanic crust.

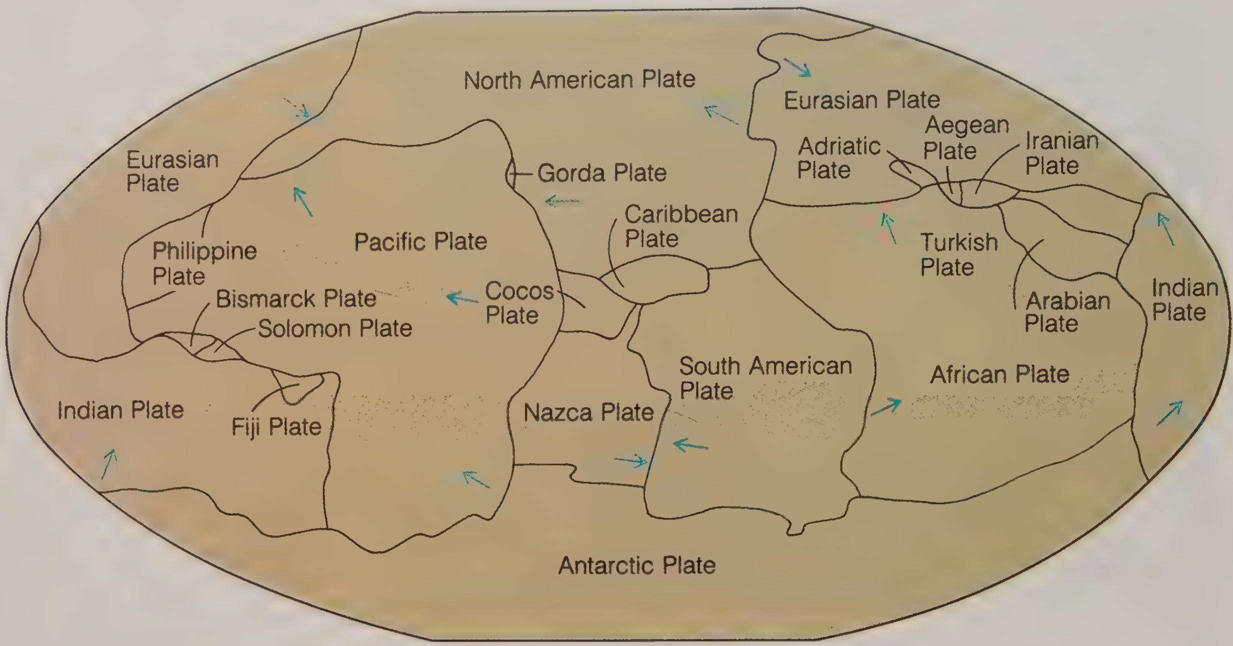


Figure 10-30. The earth's surface is made up of seven major plates and several smaller plates. What do the arrows indicate?

What does a shallow-focus earthquake indicate about the depth of a subducting plate?

Library research

What are magnetic field anomalies? Find a picture that shows actual anomalies over a ridge (for example, the Reykjanes ridge south of Iceland).

2. The youngest rocks in the sea floor are in the rift zone. The rocks get older with increasing distance away from the central rift zone.
3. Ocean sediments increase in thickness and age with increasing distance away from the central rift zone.
4. Studies of rock magnetism show a symmetrical pattern on both sides of the central rift zone. This pattern can best be explained by sea floor spreading.
5. The focuses of earthquakes follow a definite pattern along a subducting plate. (See Figure 10-31.) Shallow-focus earthquakes are produced nearest a deep sea trench. The shallow focus indicates an area of subducting plate that is above the low-velocity zone of the earth's upper mantle. Earthquakes of intermediate focus occur farther from the trench. This indicates that at this location the plate is deeper, in the low-velocity zone. Deep-focus earthquakes occur farthest from a trench and indicate that the subducting plate is below the low-velocity zone.
6. Detailed mapping of rock formations in western North America, from Alaska to Baja California, reveals a pattern of growth for the North American continent. Some rocks appear to have formed originally as part of a different continent. Others are from oceanic volcanic islands or large chunks of sea floor. This pattern of "foreign" rocks along the margin of a continent presumably is the result of convergence between two plates. At the juncture, low-density rock fragments will tend to

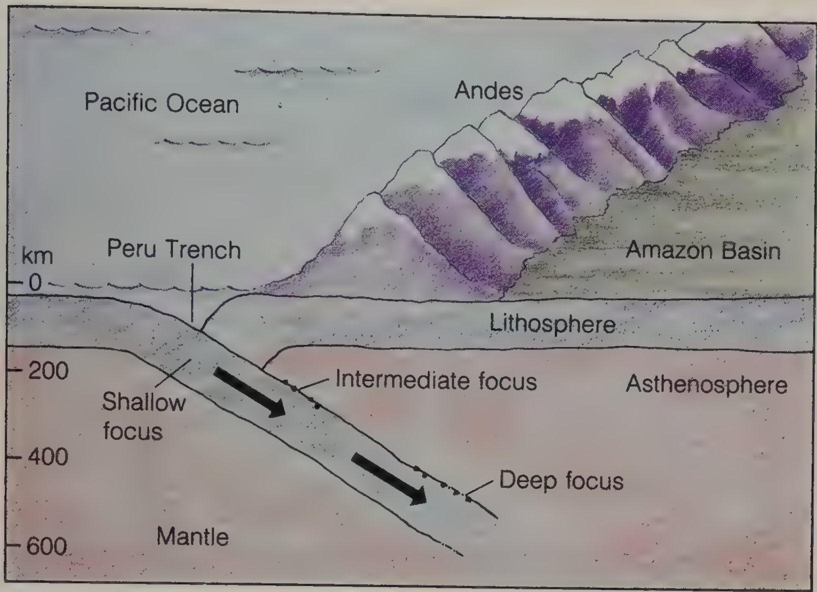


Figure 10-31. Which earthquakes occur farthest from a trench—shallow-focus or deep-focus earthquakes?

float on denser, subducted crust. These fragments are, in effect, scraped off one plate to become mountains on the other.

The concept of sea floor spreading resolved Wegener's greatest theoretical problem—the friction of continents drifting over the ocean crust. No force was or is known which could overcome so much friction. According to the sea floor spreading concept, continents do move, but not by drifting. They are rafted along by basaltic ocean crust which continually forms at mid-ocean ridges from a molten state. Friction is significant at crustal plate boundaries only. The force that causes plate movements, however, is poorly understood but is believed to be heat-related convection movement in the asthenosphere. (See Figure 10-28 on page 507.)

According to the sea floor spreading theory, how do continents move?

Check yourself

1. What are the plates of the plate tectonic theory?
2. What are the seven major plates on the earth's surface?
3. Describe briefly the different types of plate boundaries.

Pangaea

According to the plate tectonic theory and Wegener's theory of continental drift, at the end of the Paleozoic Era, the continents came together and formed one single continent, a supercontinent called, by Wegener, Pangaea (pan-JEE'-uh). As rift valleys formed and extended across continental

Into what two land masses did Pangaea first break?

masses, the lithospheric plates started moving apart, ocean crust formed, and ocean water spread between land masses. The breakup of Pangaea followed the patterns shown in Figure 10-32.

According to the theory, Pangaea first broke into two large land masses called Laurasia and Gondwana. If you check your dictionary, you will find that the word *Laurasia* is made from parts of words that refer to North America, Europe, and Asia. Those three land masses were originally part of Laurasia. And Gondwana, according to the theory, included the present-day land masses of India, Australia, Africa, South America, and Antarctica. As shown in the diagram for 180 million years ago (Diagram B) in Figure 10-32, the equator serves as the dividing line between Laurasia and Gondwana. (Laurasia is to the north; Gondwana is, for the most part, to the south.)

Present-day landforms stretch back to the formation and breakup of Pangaea. Examples include the Appalachian Mountains, the Himalayan Mountains, and the Red Sea.

1. The Appalachian Mountains formed during the mid to late Paleozoic Era. The compressional forces responsible probably were caused when Africa and Europe converged on North America as Pangaea was forming.

2. The Himalayan Mountains were formed when India and Asia collided in the Cenozoic Era. After the breakup of Pangaea, India converged with Asia and part of India subducted under Asia. Because of the double thickness of continental crust, the Himalayas are the highest landforms on the earth.

3. The Red Sea was formed twenty million years ago when a

Table 10-2. The earth's history can be divided into different time groupings which are called eras. During which era were the Appalachian Mountains formed? How many millions of years ago might that have been?

Major Divisions of Earth Time

Era	Length of Time
Cenozoic	From 65 million years ago to the present
Mesozoic	From 255 million years ago to 65 million years ago
Paleozoic	From 600 million years ago to 255 million years ago
Precambrian	From the beginning of the earth to 600 million years ago

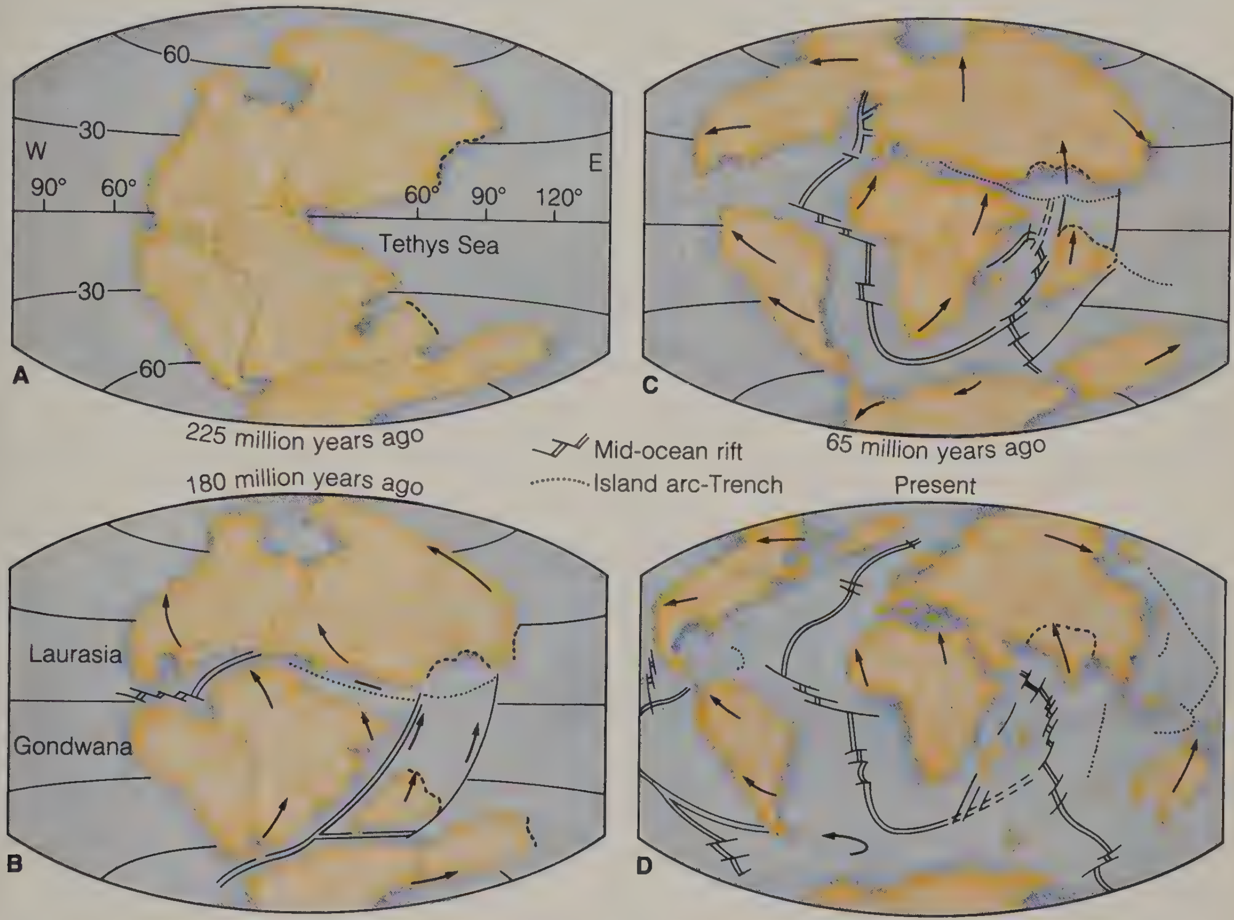


Figure 10-32. How did the position of India change from Pangaea to the present?

rift valley developed between Africa and Arabia. In the future, the Red Sea may widen into a major ocean. As it does, the rift valley of Africa, which is still above sea level, may be split enough to form a new seaway.

The collision and moving of plates has probably been taking place throughout most of earth history and will probably continue as long as there is heat and motion in the asthenosphere. While the movement continues, continents will split and collide, mountains will be uplifted, volcanoes will erupt, and earthquakes will occur. And most of this activity will be concentrated along plate boundaries.

Check yourself

1. What was Pangaea?
2. What mountain range formed as Pangaea formed?
3. What has been the history of the Red Sea, and what might it become in the future?

Activity Reconstructing Pangaea

Materials

map of world today
tracing paper
scissors
glue, rubber cement, or cellophane tape
map of Pangaea (See Figure 10-32 on page 513.)

Purpose

To study the relationships between the present continents and Pangaea.

What to Do

1. Trace and label the continents as they appear today from a world map.
2. Cut out the continents at the seaward edge of the continental margins.
   a) Separate India from Asia, cutting along the Himalayan Mountains.
   b) Separate Saudi Arabia from Eurasia.
   c) Separate Greenland from North America.
3. Cut away the following post-Paleozoic features:
   a) Parts of southeast Asia, including Indonesia, Malaya and Borneo.
   b) The Afar triangle (in East Africa on the Gulf of Aden at the entrance to the Red Sea).
   c) The part of Central America from Guatemala to South America.
4. The "Y" between Spain and France was opened up since the Paleozoic. Reconstruct the late Paleozoic position of Spain by cutting between France and Spain and rotating Spain.
5. Reconstruct Pangaea by putting the pieces together, using a map of Pangaea as a guide. Tape or glue your pieces in place, after you are sure of the position of each piece.

Question

How does your finished reconstruction compare with those made by other students in your class?

Conclusion

How does constructing a model help to show relationships between the modern continents and Pangaea?

Step 2

Step 5

Careers Seismologist / Construction Inspector

Seismologist Seismologists (sīz-MAHL′-uh-jists) study waves in the earth that are produced by earthquakes and other disturbances. They use instruments such as the seismograph, which magnifies movements in the earth and records the data on a graph.

Seismologists locate earthquakes and seek methods for predicting and controlling them. They also learn about the structure of the earth, explore for oil and minerals, and provide information to the construction industry.

Many seismologists work in the field. They might set off explosions and measure waves reflected from the rocks beneath the earth's surface. Others perform their work in laboratories and offices.

Seismology is a branch of geophysics, which is the physics of the earth and its atmosphere. To become a seismologist, work toward a college degree in geology, physics, or geophysics. Your high school preparation should include math, physics, and earth science.

Seismologists can tell much from the data recorded on a seismograph.

Construction Inspector Federal, state, and local governments employ inspectors for all types of construction. There are inspectors for electrical systems, mechanical systems (such as plumbing), public works (such as roads), and buildings.

Construction inspectors who specialize in buildings first review the plans for a building. They make sure that the plans follow building codes and zoning regulations. They indicate any special construction techniques such as would be necessary in earthquake-prone areas. They also determine whether the building might cause any harm to the environment.

Inspectors usually visit a construction site several times. If they find something wrong and it is not corrected quickly, they can issue a "stop-work" order. They write a report after each inspection.

To become a construction inspector, you should take math, drafting, and English in high school. Then you might work in the construction industry for a few years before applying to be an inspector. You will increase your opportunities if you take some college courses in engineering or architecture.

Construction inspectors visit construction sites to make sure that buildings are constructed properly.

Activity Simulating Sea-Floor Spreading

Materials

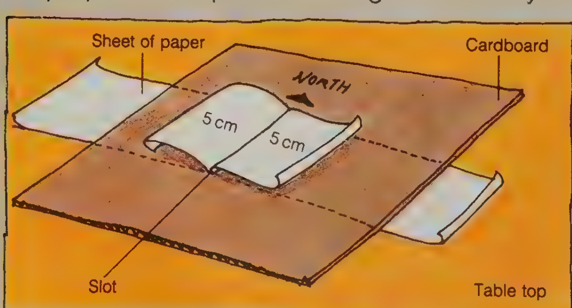
2 large pieces of corrugated cardboard
6 sheets of typewriter paper
single-edge razor blade or sharp knife
bar magnet
magnetic compass
colored markers or pencils, black and red
roll of waxed paper
cellophane tape

Purpose

To simulate sea-floor spreading.

What to Do

1. Set up the model as shown in the diagram. Tape 3 sheets of typewriter paper together into a sheet 28 cm wide by 65 cm long.
2. Label one edge of the cardboard north, making sure that the slot points in a north-south direction relative to your label.
3. Slide the paper sheets through the slot. Leave about 5 cm of paper showing on the surface on each side of the slot.
4. You will now perform a series of steps which you will repeat six times. First, note that the unmarked paper on each side of the slot represents ocean crust that has formed during a time when the earth's magnetic field was in a constant direction. Have a member of your team close her or his eyes, pick up the bar magnet, and place it on the paper with the length of it parallel to the slot. (The purpose is to place the magnet randomly so that it does not have the same end always pointing in the same direction.)



5. Place the compass on top of the bar magnet and note which way the north end of the needle points. If it points toward the north on your cardboard, label the paper with black N's (for normal polarity). If the needle points toward the south, label with red R's (for reverse polarity).
6. Measure and record the total width of the exposed portions of paper on both sides of the central ridge area.
7. Tear off a sheet of waxed paper just long enough to stretch across both of your labeled sheets of paper (the width of the ocean basin of Step 6). Tape the waxed paper securely to the paper beneath it. (Each succeeding time you do this step, you will need a longer piece of waxed paper to cover any previously laid-down waxed paper as well as the area just formed.)
8. Carefully cut the waxed paper right down the middle of the slot. The waxed paper has to be cut completely in half. A team member can keep the waxed paper stretched tight while another member cuts the paper.
9. Grasp each sheet of paper and pull them apart, exposing another 3 or 4 cm of unmarked paper on each side of the slot.
10. Return to Step 4. Repeat 4-9 six times.

Questions

1. How do the patterns of magnetic reversal compare on each side of the slot?
2. Which layer of waxed paper represents the oldest sediment?
3. What happens to the age of the waxed paper that is in direct contact with the marked paper from the slot position outward?

Conclusion

Why did you need to cut the waxed paper completely in half as part of your simulation? (Hint: see page 508.)

Section 3 Review Chapter 10

Check Your Vocabulary

asthenosphere	rift zone
continental crust	rigidity
discontinuity	sea floor spreading
lithosphere	subduction
low-velocity zone	theory of continental drift
mesosphere	
oceanic crust	theory of plate tectonics

Match each term above with the numbered phrase that best describes it.

1. The central part of the mid-ocean ridge where molten material rises from the earth's interior and cools into igneous rock
2. The faulting and movement of growing plates away from the central rift zone
3. The downward movement of a colliding plate margin that is being forced down toward the asthenosphere
4. A theory that views the earth's surface as composed of slowly-moving rigid plates that grow larger, collide, or move past each other with a shearing motion
5. A measure of the stiffness of a material
6. A theory that envisions the continents drifting over the top of the oceanic crust
7. Crustal rock that is basaltic, denser than granite, and about 5 km thick
8. Crustal rock that is granitic and that is between 20 and 60 km thick
9. The layer of the earth immediately below the lithosphere; includes the low-velocity zone; hot and relatively soft
10. The layer of the earth immediately below the asthenosphere; very hot and under very high pressure; moderately rigid
11. A zone in the earth's upper mantle that can slow down both P-waves and S-waves
12. A boundary between two divisions of the earth's interior; indicated by sharp changes in earthquake wave velocity
13. The earth's crust plus part of the upper mantle; relatively cool and rigid

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The earth layer that behaves like a liquid is the _?_.
   a) mantle c) inner core
   b) crust d) outer core
2. Subduction occurs along _?_.
   a) trenches
   b) transform faults
   c) rift zones
   d) mid-ocean ridges
3. _?_ is credited with being the founder of the theory of continental drift?
   a) J. Tuzo Wilson
   b) Alfred Wegener
   c) Arthur Holmes
   d) Robert Dietz

Check Your Understanding

1. Describe the theory of continental drift.
2. Describe the sea floor spreading theory.
3. Describe the plate tectonic theory.
4. What is the value of "impossible" theories in science?
5. How can you tell which of the earth's layers (lithosphere, asthenosphere, mesosphere) corresponds to the low-velocity zone?

Chapter 10 Review

Concept Summary

Volcanic activity occurs when lava, gas, or solid fragments come out of a vent in the earth's crust.

- ☐ Explosive activity is caused by viscous lavas, granitic-composition lavas, or lavas containing superheated water.
- ☐ Volcanic landforms include shield volcanoes, cinder cones, and composite cones.

Folded structures are caused by shape changes in rocks.

- ☐ Anticlines and synclines are elongate folds caused by compressional stress.
- ☐ Domes and basins are circular or oblong folds caused by up and down motion due to stress.
- ☐ Anticlines and domes are upward-arched structures, and synclines and basins are downward-arched structures.

Faults are breaks in the earth's crust along which the rocks have moved.

- ☐ In a normal fault, the hanging wall moves down relative to the footwall.
- ☐ In a reverse fault, the hanging wall moves up relative to the footwall.
- ☐ A thrust fault is a low angle reverse fault.
- ☐ Transform faults are sideways offsets in the crust associated with shear stress.

Earthquakes are caused by movement along a fault or by volcanic activity.

- ☐ Compressional (P-waves) and shear waves (S-waves) are two types of motion produced in an earthquake.

The **interior of the earth** is made of layers of different densities and rigidity.

- ☐ The layers are studied indirectly by using earthquake waves.
- ☐ The crust, the mantle, and the core are based on density differences.
- ☐ The lithosphere, the asthenosphere, the mesosphere, the outer core, and the inner core are based on differences in rigidity.

The theory of continental drift states that the continents have moved around the surface of the earth over the top of the oceanic crust.

The sea floor spreading theory states that ocean basins spread apart as the ocean crust grows at the mid-ocean ridges.

The plate tectonic theory states that the earth's lithosphere is constantly forming and being destroyed, and that the continents are slowly carried around on top of the lithosphere.

- ☐ The mid-ocean ridge is the site of ocean crust formation.
- ☐ The trenches are sites of subduction of the lithosphere.
- ☐ The continents were together as a single land mass called Pangaea.

Putting It All Together

1. How does the Circum-Pacific Ring of Fire relate to lithospheric plate boundaries?
2. How does earthquake activity relate to the plate tectonic theory?
3. What types of plate boundaries would most likely experience compressional stress? Give specific examples.
4. How do folded mountain belts relate to the plate tectonic theory?
5. How can events with a low probability be used to create a theory? Give an example.
6. Describe a sequence of events that probably occurred during the formation of the Atlantic Ocean basin.
7. The Palisades along the Hudson River in New Jersey, and the ridges in and around Gettysburg, Pennsylvania, are dark colored basaltic material that is upper Triassic in age. How might these rocks be related to the plate tectonic theory?
8. What causes the earthquake activity in the California areas around Los Angeles and San Francisco?

9. Earthquakes along the mid-ocean ridge are all shallow focus, whereas earthquakes near trenches are shallow, intermediate, and deep focus. What causes these differences in earthquake activity?
10. Make a cross-sectional diagram of the earth, showing lithospheric plates, low-velocity zone, and motion of the plates (use arrows). Label areas of plate growth, plate convergence, and plate destruction.

Apply Your Knowledge

1. Describe the hazards of an earthquake, and how the hazards might be avoided or made less severe.
2. What types of earth processes can create mountains?
3. What types of inner earth activities might cause variations in ocean basin depths (specifically, the mid-ocean ridge system, the deeper ocean basins, and the trenches)?
4. Some reports have indicated that California is going to split apart and fall into the ocean. Describe what will really happen to California according to the plate tectonic theory, and how long it may take at the present rates of change.

Find Out on Your Own

1. Using reference books, find out how the Hawaiian Islands relate to the plate tectonic theory.
2. Find out what types of rock structures are within a 300-km radius of your home, and relate this to the plate tectonic theory.
3. Make a list of the kinds of activities that people do that can create earthquakes. Include the magnitude of the earthquakes that can be generated by each of these activities.

Reading Further

Asimov, Isaac. *How Did We Find Out About Volcanoes?* New York: Walker, 1981.

Explains the nature of volcanic activities, including accounts of major volcanic eruptions. The reader shares in the process of discovery. Designed to inspire young readers in methods of learning.

Fradin, Dennis Brindell. *Disaster! Earthquakes.* Chicago: Childrens Press, 1982.

Describes a severe earthquake in 1980 in Italy and other major earthquakes. Explains causes of earthquakes, methods of prediction, and safety procedures. Beautifully illustrated.

McPhee, John. *Basin and Range.* New York: Farrar, Straus, & Giroux, Inc., 1981.

A geologic excursion from the Palisades of New Jersey westward to the Pacific. By a writer who can interest people in just about anything he chooses to write about.

National Geographic Society. *Our Violent Earth.* Washington, DC: National Geographic Society, 1982.

Describes natural disasters such as earthquakes, volcanoes, storms, droughts, fires, floods, glaciers, and avalanches. Exceptional photographs.

Navarra, John Gabriel. *Earthquake.* Garden City, NY: Doubleday, 1980.

Describes the cause and effects of earthquakes. Topics include plate tectonics, seismic waves, seismograph, Mercalli and Richter scales, tsunamis. Tells how to prepare for an earthquake and how earthquakes are predicted.

Rydell, Wendy. *All About Islands.* Mahwah, NJ: Troll, 1984.

An easy-to-read and enjoyable book about the formation of a volcanic island. Colorful illustrations.

Science Issues of Today Predicting Earthquakes

A changing earth is inevitable. Slow changes are of no particular hazard to people on a day to day basis. But slow changes such as lithospheric plate movements of 4 to 10 cm per year can lead to a buildup of stress in the earth's crust. Most crustal rocks are fairly rigid, and the friction between them allows the stress to build to rather high levels. A sudden release of the stress causes crustal movements of rock along fault zones, and the resulting energy travels to and around the earth's surface in the form of shock waves. These shock waves can be highly destructive. An earthquake in Guatemala in 1976 killed over 22 000 people and injured another 70 000. Another earthquake later in the same year in China killed nearly 650 000 people!

Predicting earthquakes is important in saving people's lives and preventing injuries. One successful prediction in 1975 in a highly populated part of China resulted in little personal injury despite widespread destruction of buildings; the people were instructed to get out of the buildings and stay outdoors. The prediction and mobilization of people came only a few hours before the earthquake struck the area.

To be most useful, earthquake predictions need to accurately determine the time of the tremor and its intensity. Several phenomena seem to be helpful in making predictions, but none of them is foolproof. For each specific locality, a detailed understanding of the local and regional geology and of historical patterns of events that precede earthquakes is essential in earthquake prediction.

Water can play a role in triggering earthquakes. In 1962 and 1963, Denver, Colorado, had over 700 small to medium earthquakes. The number of tremors was unusually high for the area. The tremors started within an 8 km radius

of some wells that were being used for injecting liquid wastes into the ground. When the injection was stopped, so did the earthquakes. Resumption of injection was accompanied by a resumption of tremors. Water, evidently, can lubricate a fault zone and make it easier for the built-up stress to cause movement. Some scientists speculate that water injection in other fault zones might allow small movements of rock, thus releasing stress in small, non-destructive pulses. But scientists also fear that introducing water into a fault zone that has not moved in a long time might trigger a massive release of energy and cause much destruction.

Lithospheric plates are constantly creating stress in the earth's crust. As long as earthquakes are a threat to our safety, scientists will continue to study ways to decrease the danger.

Past, Present, and Future

Unit 6

The earth's past stretches back billions of years. Preserved in the earth's rocks are records of changes that have taken place over that enormous expanse of time. Changes in life forms, changes in the earth's crust, changes even in the relative positions of the earth's continents can be detected or inferred from a study of the earth's rocks.

The earth's present and future will also be shaped by natural earth processes. Increasingly, however, the human population is having an effect on the earth as a planet, as a source of needed materials, as an environment for life. In a sense, the present use of the earth is determining the earth of the future.

Chapter 11

The Earth's Geologic History

Section 1
Unraveling the Rock Record

Assumptions play an important part in science. Even the most scientific of conclusions will often involve one or more assumptions.

For example, in order for scientists to interpret the rock formations in the earth's crust, scientists assume that the earth processes that occur today have been occurring throughout earth history.

In this chapter, you will become acquainted with some of the basic assumptions underlying our present understanding of earth history.

Section 2
Dating the Rock Record

Throughout human history, various estimates have been offered for the earth's age. Some estimates expressed the earth's age in thousands of years. Other estimates expressed the earth's age in millions of years. The most recent scientific methods place the earth's age at about 4.6 billion years. To try and imagine the length of time indicated by 4.6 billion years is no easy task.

Section 3
A Parade of Life Forms

By means of certain assumptions, scientists have been able to reconstruct earth processes that are presumed to have been occurring throughout earth history. By means of assumptions, scientists have also been able to reconstruct a sequence of life forms that have been found on the earth at various periods of the earth's long history. Scientists have also attempted to explain changes which have occurred among life forms over long periods of time, taking into consideration processes that are being observed to take place in and among present-day life forms.

For our knowledge of life forms that occurred in the earth's distant past, we must examine the earth's rocks. The fossilized dragonfly pictured on the facing page was found in the Green River Formation, Garfield County, Colorado. What kinds of information can scientists learn from such a fossil?

Unraveling the Rock Record Section 1

Section 1 of Chapter 11 is divided into seven parts:

Uniformitarianism

Assumptions in science

The principle of superposition

The principle of original horizontality

The principle of faunal succession

Darwin's theory of evolution by natural selection

Studying the earth's crust

Figure 11-1. These animals were painted on the inside of a cave in Lascaux, France, about 17 000 years ago. They are one of the earliest records left by long-vanished people. The rock on which the paintings appear, however, traces back much farther into the earth's distant past.

The story of the earth's past stretches way back into prehistory—the period before the earliest drawings and writings left by long-vanished peoples. Even though there are no historical records of the earth's distant past, there are records of prehistoric events in the rocks of the earth's crust. From these geologic records, it is possible to reconstruct how the earth probably appeared in prehistoric times.

What period of time does the word *prehistory* refer to?

Uniformitarianism

In science, certain rules or principles are followed in the study of nature. Scientists observe and record nature, gathering their data or information through direct observations. But direct observations are made only in the present. How, then, is it possible for science to say anything about the earth as it was before observations were recorded?

Scientists do more than just record observations. They also study and compare observations made by others. Sometimes patterns become evident. We may safely assume that some of these patterns have held true throughout all of earth history. For example, certain physical, chemical, and biological processes are the same today as they were during the time of scientists who lived hundreds of years ago.

In the earth sciences, it is assumed that past earth processes such as volcanism and erosion can be explained by the same chemical and physical laws used to explain earth processes in the present. In fact, many of the same earth processes directly observed today probably occurred in the past. This kind of sameness or uniformity through time of earth processes that scientists take for granted is called **uniformitarianism.**

What kind of uniformity is taken for granted in the assumption of uniformitarianism?

Uniformitarianism is an assumption that scientists make. Scientists assume that the earth processes occurring today are the same as those that have always occurred. Time machines that would take us into the past or the future do not exist. The only direct evidence that scientists have of the earth's past is the pattern of the earth's rocks. Whenever a scientist can connect patterns in the rock record to an earth process—rocks in layers to repeated flooding, for example—that scientist can go beyond the present of direct observation.

The assumption that the laws of chemistry and physics are constant through time and place is one of the primary assumptions of all science. It forms the basis of the way that scientists study and explain past and present events and predict future events.

Check yourself

1. How is uniformitarianism used by scientists?
2. List the kinds of processes that uniformitarianism refers to.
3. What kinds of activities are used in a scientific investigation?

Assumptions in science

It may surprise you to think that scientists can accept something as far reaching as uniformitarianism. Once they do that, then a lot of other assumptions can be made. In fact, each time a process in the present is applied to the past or the future, scientists are making an **assumption.**

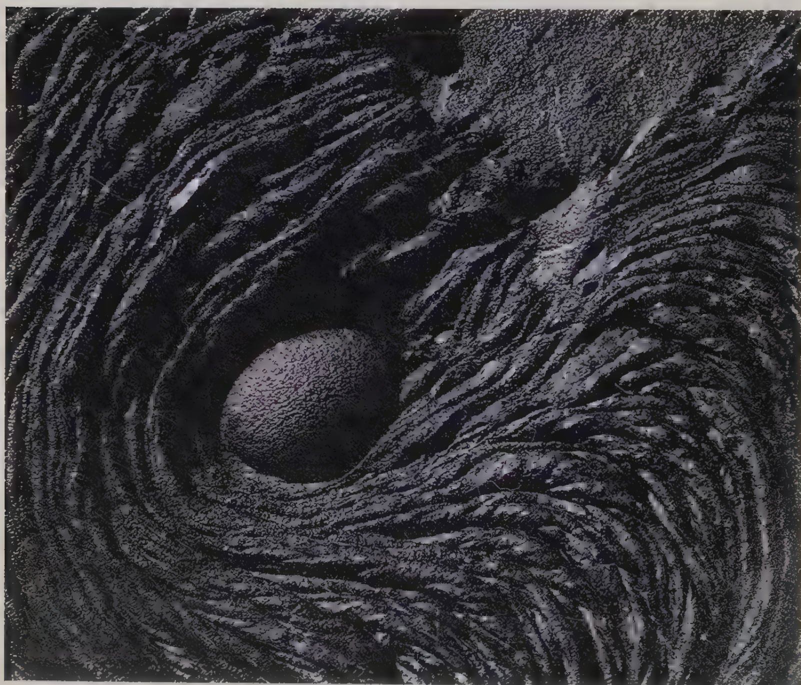


Figure 11-2. This rock formation (on James Island, Galapagos) was caused by a lava flow. Scientists assume that the volcanic activity that caused this lava flow has been occurring throughout the earth's history.

Scientists have no way to prove that an assumption like uniformitarianism is true. Does this mean that making assumptions in science is bad? Not at all, as long as everyone recognizes that they are assumptions. Whether or not a person wants to accept an assumption is a personal matter. If people could not remember the past or anticipate the future, then there would be no need for science. But people are capable of such thought processes. So, in order to understand science, it is important that people know the basic assumptions of science. Also, it is important to realize that some assumptions may need to be changed. It is always possible that more observations or further thinking will cause scientists to revise certain assumptions.

Some assumptions in science are more obvious than others. Certain assumptions have even become so well accepted that they are considered to be **principles** or laws. This is true of many assumptions that are basic to an understanding of the earth's history. Uniformitarianism is perhaps the most basic and therefore the least changeable assumption in earth science. Three other assumptions now basic to understanding the earth's long past are 1) the principle of superposition, 2) the principle of original horizontality, and 3) the principle of faunal succession. We shall examine how each of these three principles is used repeatedly to connect the patterns in the rock record to earth processes.

Library research

Who were the Plutonists and the Neptunists and how do they relate to our present understanding of the earth's rocks?

What is a scientific principle or law?

Check yourself

1. How do assumptions help a scientist?
2. Describe the relationship between an assumption and a principle or law.
3. What can cause a scientist to change an assumption?

The principle of superposition

Information about the earth's history is contained in rocks. Rock that forms the earth's crust is often formed in layers. When geologists study rock formations, they need to know the relative ages of the layers of rock. Which layer is the oldest? Which layer is the youngest?

Activity Verifying the Principle of Superposition

Materials

4 playing cards (No two should be the same.)
textbook
clock or watch that indicates seconds

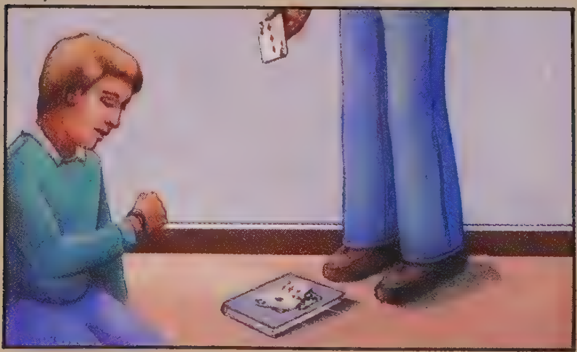
Purpose

To examine the principle of superposition.

What to Do

1. Choose which partner will be the recorder and which will drop cards onto the textbook one at a time.
2. Begin to drop the cards. Make sure that the second card is dropped on top of the first card. Each succeeding card should be on top of the previous card.
3. The recorder will record each card and the time that it landed on the book or other card, to the nearest second.
4. After all four cards have been dropped and the times recorded, list the sequence of cards on the book.

Step 2



5. Now, holding the cards tightly against the book, turn the cards and the book upside down and list the sequence. (Remember, the book is now on the very top.)

Questions

1. When you first drop the cards, which card is the "oldest" card? Which card is the "youngest" card?
2. How do your two sequence lists compare in the ordering of the cards from top to bottom?
3. What would happen to the top-bottom relationship of the cards if the book and cards were tilted upright and held in a vertical position?

Conclusion

How might you relate this activity to movement in the earth's crust?

Step 5

Card Dropped	Time of Landing
1.	
2.	
3.	
4.	

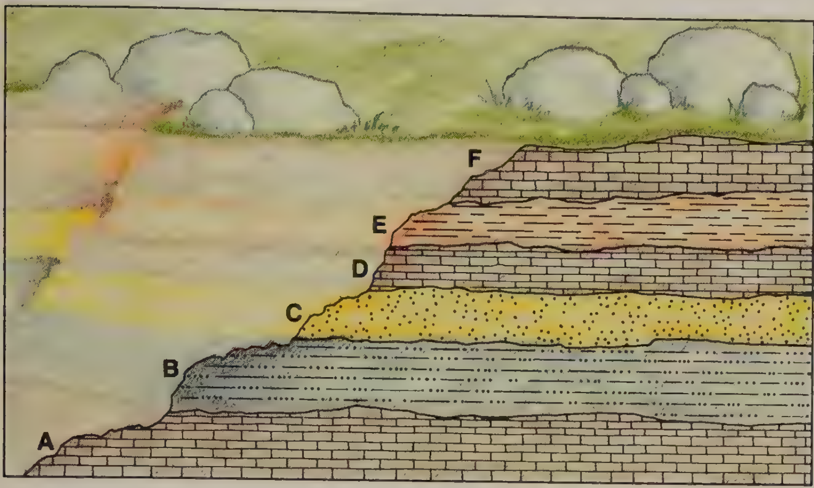


Figure 11-3. Which rock layer is the oldest—Layer A or Layer F?

According to the **principle of superposition,** the oldest rock in any undisturbed sequence of rocks is the rock on the bottom, if the rocks are lying in a nearly original position. According to this principle, Layer A in Figure 11-3 is the oldest layer of rock. That is to say, Layer A was the first layer to be deposited. It had to be in place before the next layer above could be deposited. Therefore, each rock layer that has rock layers above and below has younger rock above and older rock below.

In an undisturbed sequence of rock layers, which layer is the oldest?

The word *superposition* comes from two Latin words that mean to place above *(super)*. One of the basic assumptions behind the principle of superposition is that rock forms on top of previously existing rock. This is true of sedimentary rock. This is also true of lava flows, which occur on the earth's surface. But it is not true of magmas. Although related to lava, magmas can squeeze in between layers of previously formed rock and harden, forming a new layer of rock between older layers. Another exception is that the principle of superposition is not necessarily true for metamorphic rocks.

If rock layers have been upended or turned upside down by movements within the earth's crust, the principle of superposition may be difficult to apply. Scientists can check for this by carefully studying the rocks, both in the field and in the laboratory. Mud cracks and ripple marks made by waves are often preserved in the rocks. These are useful tools that help in telling tops from bottoms of rock layers. As shown in Figure 11-4, mud cracks are widest at the top, and form a V shape downward. As shown in Figure 11-5, wave-created ripple marks have sharp ridges. If buried beneath other rock layers, these ridges always point toward younger rock. When originally formed, the ridges pointed up. If you found rock

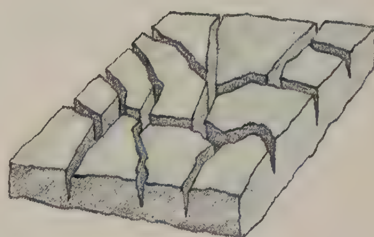


Figure 11-4. The points of V-shaped mud cracks point downward.

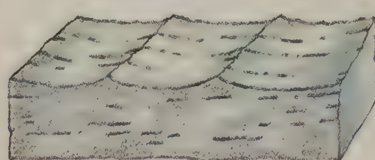


Figure 11-5. The points of ripple marks point upward toward younger rock.

layers in which wave ripples pointed down, you would know that those layers had somehow been turned upside down.

Check yourself

1. What basically does the principle of superposition say about the ages of rocks?
2. What features indicate if rock layers are right side up?

The principle of original horizontality

Sedimentary rocks were originally formed by sediments that were deposited, usually by wind or water. According to the **principle of original horizontality,** it is assumed that the sed-

Figure 11-6. These sand dunes are located in the Namib Desert, South West Africa. Very little of a sand dune's surface is horizontal.

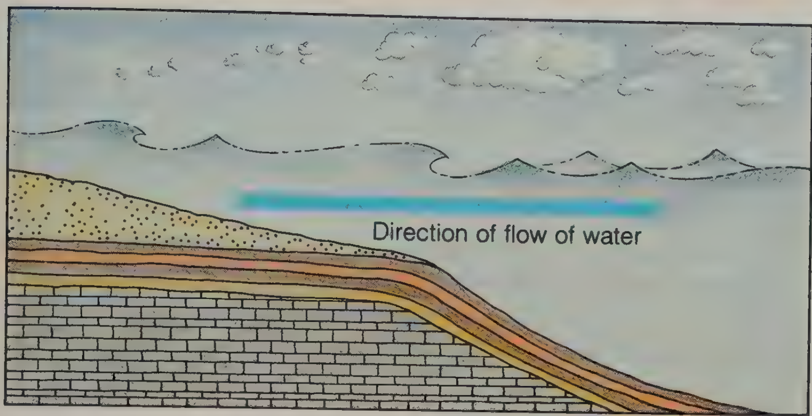


Figure 11-7. Are the layers of sediment in a delta horizontal where the river first enters a lake or ocean, or are they horizontal farther out?

iments were deposited in layers that were parallel to the earth's horizon. By comparing the rock layers to the earth's horizon, you can see that the rock layers in Figure 11-3 on page 529 are horizontal.

In order for the layers to be horizontal, the rate of deposit is assumed to be the same over the extent of the rocks. It is also assumed that the surface on which each layer of sediments was deposited was horizontal to begin with. These assumptions require circumstances that were fairly common in many parts of the world during earth history. There are, however, two common exceptions: sand dunes and deltas.

In sand dunes, the layers of sediment are parallel to the top surface of the dune. The wind blows the sand up one side of the dune. The sand particles fall down the other side, which is sheltered from the wind. As shown in Figure 11-6, very little of a sand dune is in a horizontal position.

Where are most of the sediments in deltas deposited?

In deltas, most of the sediments are deposited where a stream or river enters a lake or ocean. There, the underwater surface of the delta is nearly horizontal. But farther out in the ocean, where less sediment is falling and the ocean bottom is dropping, the layers are angled downward. The sediment layers are formed parallel to the surface of the delta. As a result, some of the layers of deposit are horizontal, and some are not.

Over great distances, deposition of sediments is usually not consistent. In some cases, this is obvious because layers become thinner or thicker or have sloping surfaces. In other cases, however, the change is so minor over such great distances that it is discovered only by careful fieldwork and mapping.

Check yourself

1. What rock types agree with original horizontality?
2. What conditions are assumed for original horizontality?

The principle of faunal succession

What does the word *fauna* mean?

What are fossils?

Throughout the vast stretches of the earth's past, animals of many different kinds and sizes and shapes have appeared on the earth's surface. Some forms of animals survived on the earth for a long period of time while other forms of animals survived for only a relatively short period of time. Some forms became extinct while other forms developed into animals that are still living on the earth today. According to the **principle of faunal succession,** the different forms of animals throughout the earth's past are thought to have occurred in a definite order or sequence. (The word *fauna* means "all the animals that live or lived together at a certain time or in a certain place.")

Information about faunal succession is based on the fossil record found in the earth's rocks. When animals die, their skeletal remains may become preserved in sediments that in time are turned into sedimentary rocks. An impression of the animal remains can be preserved in the rock even though the animal remains have long since disappeared. Skeletal remains or impressions of previously living life forms in rock that formed before written history are called **fossils.**

Hard parts of animals are the most common fossils. Fossils of shelled sea animals are common. Fossil jellyfish are rare. This suggests that most fossils were formed slowly. Yet there are fossils of earthworms and other soft-bodied organisms, which may have died in a place protected from decay organisms. Or sometimes, when a volcano erupts, living organisms become covered over. As the volcanic material hardens, the organism becomes a fossil in rock.

Fossils are often used to identify the relative ages of rock layers in widely separated locations around the earth. Sediments that were deposited one hundred years ago contain the remains of animals that died one hundred years ago. Sediments that were deposited five thousand years ago contain the remains of animals that died five thousand years ago, and so forth.

Certain kinds of fossils serve as index fossils or guide fossils. They provide a fast way for geologists to determine the age of

rock layers relative to other rock layers. To serve as an **index fossil,** a fossil must meet two requirements. First of all, the fossil must be of a life form that appeared on the earth during only a relatively short period of time. That way, any layer of rock containing that fossil can be identified as belonging to a certain period of time in the earth's past. And secondly, an index fossil is one that must appear in rock layers in distant places around the earth. That way, relative ages of rock layers in widely separated areas can be established.

One example is a fossil trilobite (TRĪ′-lō-bīt′) that was found in a layer of shale in the Grand Canyon. The trilobite belongs to a particular variety resembling those found in rock layers in Wales that have been identified as Cambrian (a time period of the earth's past between 500 million and 600 million years ago.) The trilobite fossil in the Grand Canyon therefore serves as an index fossil that leads scientists to infer that the shale layer in the Grand Canyon is about the same age as the Cambrian rock layers in Wales.

Figure 11-8. Fossil trilobites have been found in rock layers in distant places around the world.

Another useful feature of index fossils is that some of them accumulated in many different environments. These index fossils are especially valuable because they are now found in many different types of sedimentary rocks. These index fossils enable scientists to identify similarities in the age of rock layers that differ widely in other outward appearances.

In order to apply the principle of faunal succession, scientists first make the following four assumptions:

1. The general sequence of fossils in the earth's rocks will be similar everywhere.
2. Rock layers of different ages will contain different groups of fossils.
3. The principle of original horizontality is a valid assumption.
4. The principle of superposition is a valid assumption.

Using the four assumptions just listed as rules to govern their thinking, the scientists have made the following inferences:

1. Rock layers of the same type and age in different parts of the world contain similar types of fossils.
2. Rock layers that contain similar groups of fossils are about the same age.

There are problems with the principle of faunal succession and with the use of index fossils. Both are based on the assumption that all of the same type of organisms lived and died about the same time in earth history everywhere on the earth.

Activity Reading a Rock Record

Materials

diagram and key that accompany this activity

Purpose

To learn to examine a geologic cross-section for clues to faunal succession.

What to Do

Examine this cross-sectional view through some rocks. Notice that the boundaries between the different types of rocks (shale, sandstone, and limestone) are not parallel to the time lines T0 through T4. This is caused by a geographic shifting of the environments through time and is found often in nature.

Questions

1. What do the horizontal marks within each rock illustrate?
2. What letter represents a fossil or an animal that lived only in clay muds? Of an animal that lived only in a sandy beachlike environment? Of an animal that lived only in the lime muds? Of an animal that lived in three different environments?
3. What letter(s) represents fossils that are found during time zone T0-T1? During time zone T1-T2? During time zone T2-T3? During time zone T3-T4?
4. What letter represents a fossil that is found in only one time zone? What name is given to this type of fossil?

Conclusion

How does the age of the sandstone change from the left side of the diagram to the right side?

Key

Shale (formed from clay muds in a bay or lagoon where the water was quiet and there was little wave action)

Limestone (formed offshore from lime muds)

Sandstone (formed from beach sands or shallow-water sands in an area where there was much wave action)

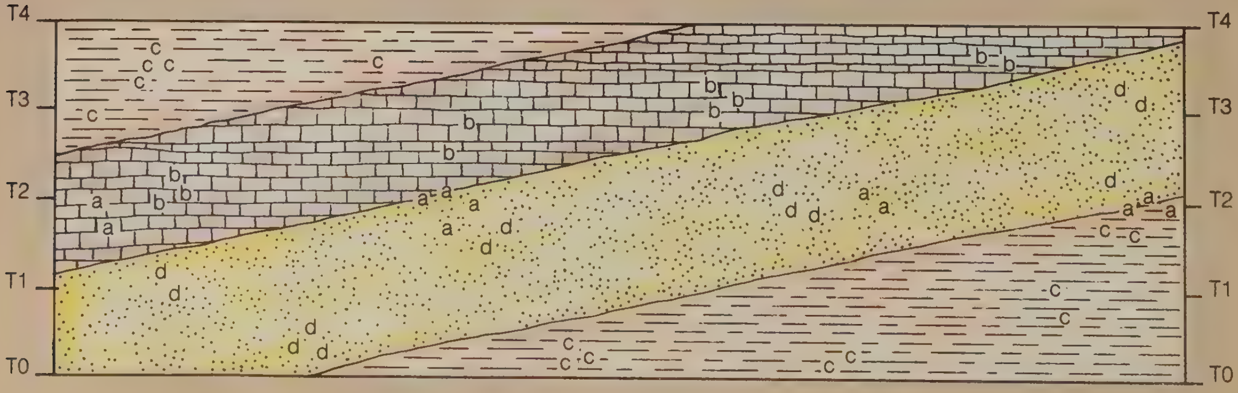
T0 to T4 Time lines (sequenced from oldest [T0] to newest [T4])

a Fossil of one kind of animal

b Fossil of a second kind of animal

c Fossil of a third kind of animal

d Fossil of a fourth kind of animal



For some fossils, this assumption may not be valid over geologic periods of time. That is because organisms will migrate to new areas as environmental conditions change. Once they have migrated, their remains probably will not be accumulating in the area they left. Depending on the type of organism and the speed of the environmental change, the migration may be slow or fast. Because of these types of changes, determining whether or not a fossil is an index fossil requires careful investigation and evaluation of the rock record over a wide area.

Library research

What other examples of in-between life forms have been found in the rock record?

Check yourself

1. On what four assumptions is the principle of faunal succession based?
2. What are the two basic inferences of the principle of faunal succession?
3. What is a fossil?
4. List the special properties of an index fossil.

Darwin's theory of evolution by natural selection

For the last two centuries, scientists have been searching and studying fossils in an attempt to unfold the story not just of the geologic earth but of the life forms on the earth. Based on a vast amount of data and research, these scientists have concluded that many species of living things have changed, or **evolved,** over time. They have also concluded that modern species of plants and animals have descended from earlier forms.

Based on fossil evidence, what have scientists concluded about life forms on the earth?

What could cause such a great change in living organisms over so many millions of years? What made it come about? Several theories have been proposed during the last two centuries. (A **theory** is a working statement that is intended to be tested and modified, added to, or replaced.) One of the most widely accepted up to now has been Charles Darwin's theory of evolution by natural selection as explained in his book *Origin of Species* (It is said that the entire first edition, which appeared in 1859, sold out in one day.)

Figure 11-9. This illustration shows Charles Darwin, as a young man, examining fossils in South America.

Library research

Archaeopteryx and *Dimetrodon* are capitalized and printed in italic type. What does this indicate?

In 1831, at the age of 22, Darwin set sail aboard the H. M. S. *Beagle* on a five-year voyage that took him from his native England to islands in the Pacific, to the coast of South America, and to Australia. During his extensive study of the plants and animals observed on his voyage on the *Beagle,* he noticed certain likenesses and differences among members of closely related species. To explain his findings, he developed a theory of evolution by natural selection. The main ideas of Darwin's theory of evolution by natural selection are as follows:

1. Individual differences are always occurring among members of the same species. For example, certain birds might have sharper beaks, better vision, or better hearing than other members of the same species.

2. Members with certain features, or traits, may be able to satisfy their needs better than others. If the individuals that have these helpful traits are more successful in producing offspring, then, in time, more and more members of the species will have these helpful traits.

3. Eventually, most members of the species in a certain area will have these helpful traits, causing a significant change in the species, or even becoming a new species.

Fairly definite evidence favoring Darwin's theory has been found among microorganisms and, to some extent, among insects. Huge populations of bacteria with different traits (usually resistance to a certain drug) develop very quickly, replacing others that do not possess the trait. Another example can be found among housefly populations that were subjected to the insecticide DDT. Those flies most resistant to the insecticide survived and passed this resistance on to their offspring. Now entire populations of flies are unaffected by DDT.

Darwin's theory of evolution by natural selection leads a person to expect that in-between life forms occurred in the development of a species. Some scientists believe *Archaeopteryx* (ar′-kee-OP′-ter-iks′) to be such an in-between form. (See Figure 11-10.) *Dimetrodon* (dī-MET′-ruh-don′) appears to be another example of an experimental life form. *Dimetrodon,* pictured in Figure 11-28 on page 570, was a reptile that had a temperature-regulating mechanism, although quite unlike that found in birds and mammals.

Figure 11-10. *Archaeopteryx* was an ancient organism that had feathers and limb structures like a bird. It also had a skull, teeth, and solid bones like a reptile.

Archaeopteryx may have been somewhere between a true reptile and a true bird. But not many in-between life forms of this type have been found in the fossil record. Among larger plants and animals, scientists have not found as many in-between life forms as Darwin had predicted. For that reason, scientists are proposing and testing other theories of evolution. Some scientists, for example, are exploring the possibility that great changes among most species may have taken place much faster than Darwin thought, leaving few or no intermediate forms in the fossil record.

In the future, it is likely that Darwin's theory will be only one of several theories that are necessary to explain the evolution of life forms.

Check yourself

1. What are the main ideas of Darwin's theory of evolution?
2. Describe one example that seems to support Darwin's theory of evolution.
3. How does fossil evidence influence concepts of evolution?

Studying the earth's crust

Within the earth's crust are many thousands of different rocks. Geologists group rocks into units called **formations.** Rocks in a particular formation share some common properties that are widespread enough to be easily recognized and mapped.

Rocks can look similar but belong to formations of different age. Geologists distinguish similar rocks by their position in a sequence of several formations.

By observing and studying the rocks and by mapping formations, geologists interpret earth history. In some places, the earth's crust has been disturbed very little over long periods of time. These areas have formations that are in their original positions. If sedimentary in origin, these areas may represent nearly continuous accumulation of sediment.

What are two ways in which the rock record in the earth's crust can be disturbed?

In other places, the earth's crust may have been repeatedly disturbed by vertical movement and erosion. Each time some rock is removed by erosion, a part of the earth's history is lost. A surface of erosion between rocks represents a gap in earth history and is called an **unconformity.** Figure 11-11 shows three unconformities—A, B, and C.

In a sequence of sediments, if sedimentation stopped for a period of time, even though there was no erosion, part of earth history would be missing. This type of unconformity (A and B in Figure 11-11) may not be easy to detect. This is especially true if the unconformity represents a very small time gap in the rock record.

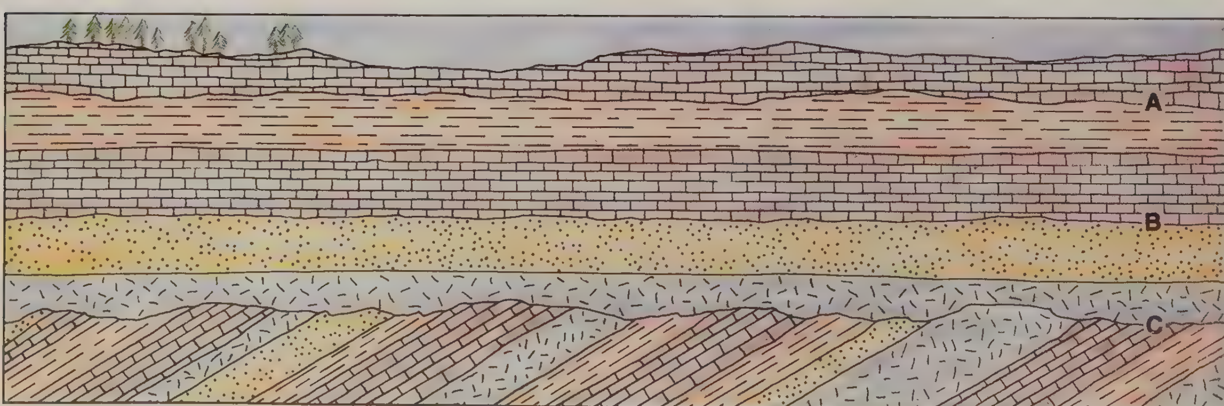


Figure 11-11. An unconformity is an incomplete surface between rock layers and represents a gap in earth history. Why is Unconformity C easier to detect than either A or B?

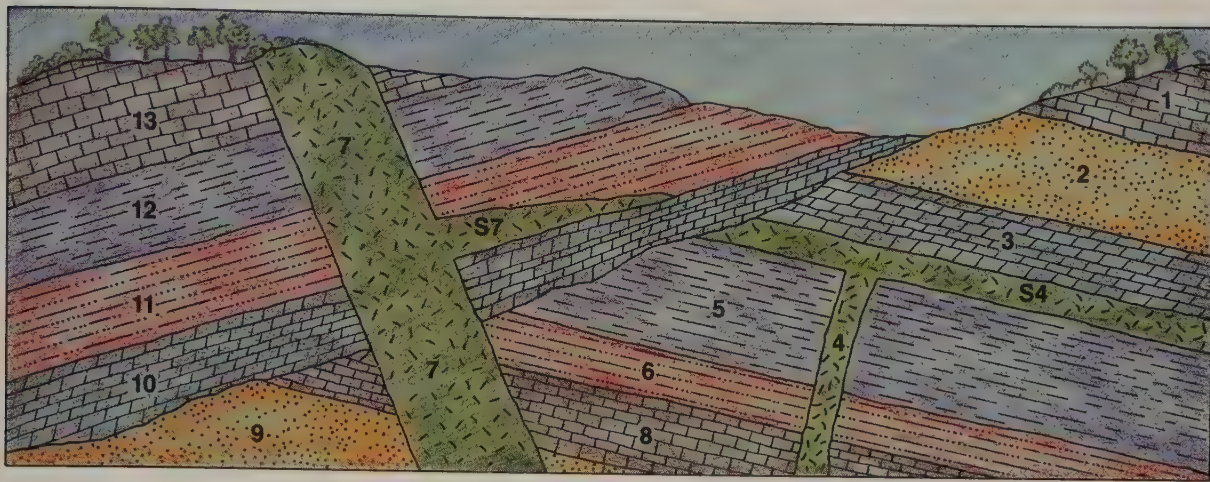


Figure 11-12. In this cross section of the earth's crust, the boundary below Layer 10 represents an unconformity. Layers 7 and 4 represent dikes. What do layers S7 and S4 represent?

Not all unconformities are so hard to detect. Sometimes the layers above an unconformity may be at a definite angle to the layers below the unconformity (C in Figure 11-11). This angular relationship makes an unconformity easy to see.

Some other angular relationships of formations also simplify the interpretation of earth history. Whenever earth movements cause breaks that cut across crustal rocks, the crustal rocks are obviously older than the breaks. Magma sometimes forces its way along the breaks or between layers of crustal rock, forming igneous rock when it cools.

How can igneous rock form in breaks between other crustal rocks?

If the resulting igneous rock is at an angle to the layers of older rocks, it is called a **dike.** Layers 7 and 4 in Figure 11-12 are dikes. A dike is younger than all the rock layers, or formations, that it cuts across.

If the resulting igneous rock is parallel to and in between layers of two other rocks, it is called a **sill.** Layers S7 and S4 in Figure 11-12 are sills. A sill is younger than either of the rock layers that surround it.

By carefully mapping rock formations and by using the assumptions mentioned in this section, geologists have been able to piece together the sequence of events that led to the formation of the earth's crust as we know it today.

Check yourself

1. In Figure 11-12, which are older—dike and sill 7 and S7 or dike and sill 4 and S4?
2. List the numbered layers of rock in Figure 11-12 in increasing order of age, from the youngest (at the top of your list) to the oldest.

Section 1 Review Chapter 11

Check Your Vocabulary

assumption
dike
evolve
formation
fossil
index fossil
principle
principle of faunal succession
principle of original horizontality
principle of superposition
sill
theory
unconformity
uniformitarianism

Match each term above with the numbered phrase that best describes it.

1. An assumption that the earth processes occurring today have always occurred
2. The taking for granted that certain processes and scientific laws are constant through time and place; for example, the laws of chemistry
3. A widely accepted assumption that has become basic to scientific thinking; a law
4. The scientific principle that states that the oldest rock in any undisturbed sequence of rocks is the rock on the bottom
5. The scientific principle that assumes that the sediments forming sedimentary rocks were deposited in layers that were parallel to the earth's horizon
6. The scientific principle that assumes that the different forms of animals throughout the earth's past occurred in a definite order
7. The skeletal remains or impressions of previously living life forms in rock
8. A guide fossil that geologists can use to determine the relative age of rock layers
9. A unit of rocks grouped together because of common properties that are widespread enough to be easily recognized and mapped
10. A surface of erosion between rocks that represents a gap in earth history
11. A layer of igneous rock that is younger than and at an angle to the other rock layers in a formation
12. A layer of igneous rock that is younger than, parallel to, and in between two other rock layers in a formation
13. A working statement that is intended to be tested and modified, added to, or replaced
14. Undergo changes over a period of time

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. __?__ are gaps in the rock record that represent some missing earth history.
   a) Index fossils c) Ripple marks
   b) Assumptions d) Unconformities
2. The principle of superposition says that __?__ rock is on top of all the other rocks.
   a) igneous c) the oldest
   b) the youngest d) sedimentary
3. Darwin's theory of evolution is based on the concept of __?__.
   a) very rapid changes in organisms
   b) no in-between life forms
   c) slow changes and natural selection
   d) index fossils and unconformities

Check Your Understanding

1. Describe the concept of uniformitarianism.
2. What is the role of assumptions in science?
3. How do geologists determine the relative ages of different rocks?
4. Describe the principle of faunal succession.
5. What does the scarcity of intermediate organisms in the fossil record mean in terms of evolution?

Dating the Rock Record Section 2

Section 2 of Chapter 11 is divided into four parts:

Early scientific investigations

Radiometric dating

The amino acid method

Geologic time

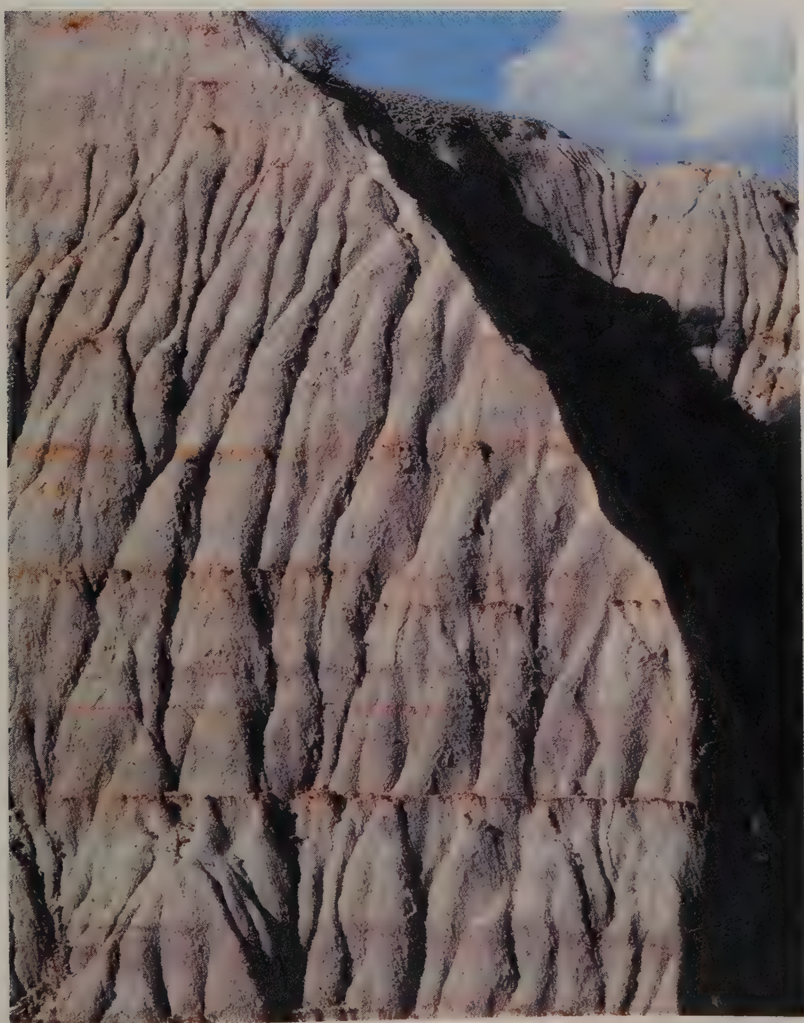


Figure 11-13. Some layering, weathering, and erosion are evident among the rock layers in this formation, photographed in Theodore Roosevelt National Park, North Dakota. Using the principle of original horizontality, what can you tell about the layers in this formation?

Time machines exist and function only in science fiction. Time cannot be seen—either by microscope, telescope, or the unaided eye. No scientist knows a perfect method of observing or calculating the age of the earth. Nevertheless, many have tried.

Early scientific investigations

How old is the earth? How old are the earth's rocks? People have tried to answer these questions for many centuries. In earlier times, answers were often based on wild guesses and superstitions. In modern times, scientists largely base their answers on the results of scientific investigations.

The accuracy of scientific investigations has improved over time. Better scientific instruments have been developed and scientists are always learning more about natural changes that are occurring. During the mid to late nineteenth century, several types of scientific investigations were conducted. Among them, they provided a wide range of possible **absolute ages,** which are ages expressed in years, for the earth.

Figure 11-14. One method of age-dating the earth was based on the amount of dissolved salt in the ocean. This method assumed that the oceans began as fresh water. Where did this method assume the salt in the present-day oceans came from?

One early method of determining the age of the earth was based on the amount of dissolved salt in the ocean. This method assumed that the oceans were all fresh water in the beginning. It further assumed that the dissolved salt in ocean water came from the weathering of rocks. This method concluded that the age of the earth could be determined by comparing how fast salt is being added to the oceans to the total amount of salt in the oceans. Using this method, different scientists calculated ages for the earth that range from 9 million to 2.5 billion years. This method failed to take into account that ocean salt is removed by natural processes and added through volcanic eruptions.

Another method of age determination involved the thickness of sediments on the earth. Assuming that sediments had accumulated at an average rate equal to present-day rates, then the absolute age of the earth could be calculated by knowing the total thickness of sediments around the world. Using this method, different scientists of the late nineteenth century obtained ages for the earth that ranged from 3 million to 1.5 billion years. We now know that sediment deposition rates are extremely variable. Also, a great number of hard-to-detect unconformities make age estimates based on sediment thickness rather inaccurate.

Another age-dating method used the life spans of different types of sea animals that were preserved in the rocks as fossils. Using this method, one scientist estimated the age of some fossil-bearing rocks at 240 million years, and these rocks were on top of many older rocks.

The most scientifically convincing method of the time was determined by Lord Kelvin, one of the world's leading physicists. This method used the cooling rates of rock material and the measured heat flow coming from within the earth. Using this method, Lord Kelvin estimated the age of the earth to be not more than 100 million years. He felt that an age of 20 to 40 million years was probably the most reasonable estimate. He based his estimate on the assumption that all the heat from within the earth was present when the earth first formed from a molten state. He did not know that the earth has been warmed by its own radioactivity and internal friction throughout its history.

Library research

What natural processes remove salt from the ocean?

Using the thickness-of-sediment method, what ages did scientists calculate for the earth?

Our Science Heritage

Smith, Cuvier, and Geologic Time

The observations of the English geologist William Smith (1769-1839) led to a breakthrough in understanding the earth's rock layers.

Classification can lead to new and better understanding of relationships among events. The systems that are used in the geologic time scale are a good example of how important classifying is to a scientist.

Geologists studying the earth's rocks had tried to come up with possible ways of sequencing the rock layers in the earth's outer crust and explaining the formation of the earth's crust. Scientists of the 1700s had tried to determine the age of a rock based on its composition. But that did not work.

An important breakthrough occurred in the 1790s when William Smith, an English surveyor who was working on the Somerset Coal Canal, happened to observe that the layers of sedimentary rocks contained characteristic types of fossils. After his work on the canal was finished, Smith continued to work as a geologic engineer throughout England. In his work, he noted that, in addition to characteristic fossils for each layer, the fossils in the layers were in order of age. He also noted that fossils in any layer did not change much from one place to another. Based on his findings, Smith published (in 1815) the first geological map of England and Wales.

Smith's publication, based on faunal succession, represents a turning point in the knowledge and understanding of the earth's rocks. He had discovered that rock layers (strata) could be identified by the fossils they contained. This discovery made it possible for scientists to determine similar ages of rock layers in different places around the world.

Smith's system of using fossils to classify rock layers was employed and confirmed in the early 1800s by Georges Cuvier, a French expert on marine animals.

In 1912, Cuvier showed that many fossil invertebrates had no known counterparts living today. He had made an important discovery. Many once-living organisms had become extinct.

The system of classification proposed by Smith and then refined by Cuvier provided the basis on which all the rock layers of the geologic time sequence in use today were later identified and named.

In all of the early methods of age determination, scientists based their work on different assumptions. The assumptions used in the cooling-earth model were considered better than those of the other age-dating methods because they were based on physical laws that could be verified in the laboratory. However, even Lord Kelvin's basic assumption had to be put aside shortly after radioactivity was discovered in 1896 by the French physicist Henri Becquerel.

Why were the assumptions of the cooling earth method considered better than those of other age-dating methods?

Check yourself

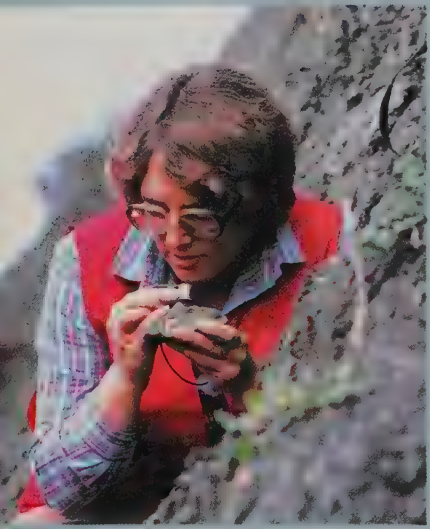
1. List the different scientific methods that were used for age estimates of the earth in the nineteenth century.
2. Describe the method Lord Kelvin used to estimate the earth's age.

Radiometric dating

Radioactivity is the ability of an element to change spontaneously into a different element by losing or gaining matter from the nucleus of an atom. The first announcement that radioactivity produced heat came from Pierre Curie and Albert Laborde in France in 1903. In Canada in that same year, Ernest Rutherford showed that the amount of heat given off is directly related to the number of atoms that are changing. Radioactivity represents a new source of heat for the earth's interior. Scientists quickly realized that the basic assumption used in the cooling earth model was not valid. They further realized that the earth might be even older than Lord Kelvin's upper limit of 100 million years.

In 1905, radioactivity was used to obtain the ages of some minerals. Some of these ages indicated an earth history many times greater than that of nearly all previous estimates. A startling revolution had begun. The age of the earth's beginning was pushed further and further back in time as more minerals and rocks were investigated. One of the oldest dated earth rocks comes from Greenland and has an age of 3.9 billion years!

How is radioactivity used in obtaining such ages? What are the basic assumptions behind the age-dating processes? How long is 3.9 billion years? And how old is the earth?



Petrologists can tell much about a rock just by looking at it.

Petrologist Petrologists (pi-TROL′-uh-jists) are scientists who specialize in the study of rocks. They obtain their samples from and below the surface of the earth. They have even obtained samples from the moon!

Petrologists work for colleges and universities, government agencies, oil companies, mining companies, and as private consultants.

People prepare themselves for this profession by many years of study. They usually major in geology in college and then complete further studies for advanced degrees in petrology. They also have to have a good background in mineralogy, chemistry, physics, mathematics, and statistics. Many petrologists got an early start by developing an interest in collecting rocks as a hobby.

Preparing to become a petrologist involves developing skills in science, math, reading, and good writing. The two most important attributes of any scientist apply to becoming a petrologist: 1) a person must be willing to work hard; and 2) a person should have an unending curiosity to know and understand more.

Refinery operators are in charge of processing crude oil into more usable forms.

Refinery Operator Refinery operators are employed by petroleum refineries. They are in charge of a processing unit, which converts crude oil (oil as it is drilled from the ground) into gasoline, heating oil, and other products. The processing, or refining, is accomplished by heating the oil and then separating it into different parts. The oil is sent through a complicated system of pipes, a furnace, a distillation (separation) tower, and other components.

Refinery operators and their helpers check on all the aspects of the processing, and they make adjustments in the rate of oil flow, temperature, and pressure. They take measurements and make adjustments by using computers and other instruments.

To become a refinery operator, you should apply for an entry-level job in a refinery after high school. From that position, you can be transferred to the operating department, where you will receive on-the-job training. Some refineries also offer classes in plant operation. You will qualify to be promoted to refinery operator when you are an experienced worker.

The changing of a radioactive element into a different element is called **radioactive decay.** Scientists assume that the rate of radioactive decay for any given element has been the same throughout all of earth history. Chemical and physical experiments on radioactive elements in laboratories have not changed the decay rates.

As radioactive elements decay, the amount of radioactive element compared to other elements decreases. Some of the other elements in the mineral come from the decay process or are related to the radioactive elements in some measurable way that allows scientists to calculate an age for the mineral. This method, which measures radioactive decay of radioactive elements, is called **radiometric dating.**

What method of age dating measures the radioactive decay of radioactive elements?

Radioactive decay is expressed in half-lives. One **half-life** is the time that it takes for one half of the radioactive material to decay. Half-lives are determined from laboratory analyses of radioactive elements. Table 11-1 lists the half-lives of five commonly used radioactive elements.

As shown in Table 11-2 on the top of page 549, the age of any object older than one hundred years can be determined. The useful range of radiometric dating varies with the different radioactive elements. The dating range is limited only by the precision and accuracy of the laboratory procedures and instruments used in the analysis.

Table 11-1. A half-life is the time it takes for one half of a radioactive material to change to its decay element through radioactive decay. What decay element forms from uranium-238?

Data Table for Five Elements Commonly Used for Radiometric Dating

Radioactive Element	Half-life	Decay Element	Material That Can Be Dated by the Radioactive Element
uranium-238	4.5 billion years	lead-206	igneous and metamorphic rocks
uranium-235	713 million years	lead-207	igneous, metamorphic, sedimentary rocks
potassium-40	1.3 billion years	argon-40	igneous, metamorphic, sedimentary rocks
rubidium-87	47 billion years	strontium-87	igneous, metamorphic, sedimentary rocks
carbon-14	5730 years	nitrogen-14	charcoal, wood, shells

Activity Measuring Radioactivity in Objects

Materials

Geiger counter
wristwatch with luminous hand or spots
alarm clock with luminous hands
digital clock or wristwatch
smoke detector
3 or 4 samples of different rocks and minerals

Purpose

To study variations in radioactivity of objects.

What to Do

1. Radioactivity is measured by an instrument called a Geiger counter. The Geiger counter detects gamma rays given off by radioactive substances. Examine your Geiger counter.
2. Geiger counters contain a special chamber of gas. Gamma rays cause an electrical current to flow in this chamber. The surges of current are amplified and counted to obtain a measure of the radioactive particles being emitted from the object. Using the Geiger counter, determine the relative intensity of radiation from each of your objects.

SAFETY NOTE: When using even slightly radioactive materials, it is a good idea to hold them at arm's length and not hold onto them any longer than is necessary.

Questions

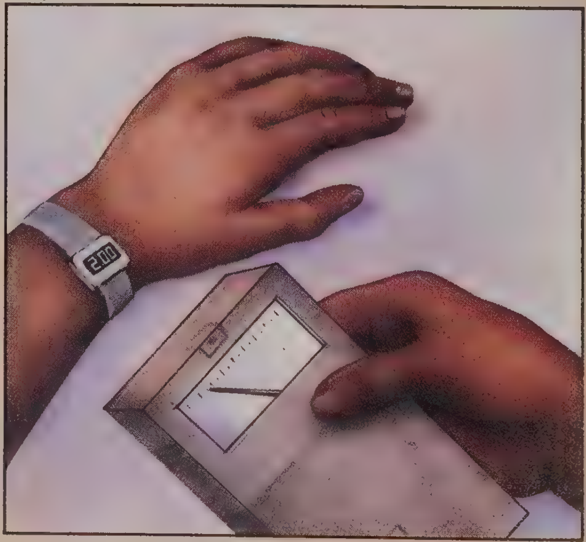
1. Which objects produced the most intense response from the Geiger counter?
2. List all of your objects in decreasing order of intensity of the Geiger counter's response.

Conclusion

How can you explain the variations in the amounts of radiation given off by the different objects?

Step 1

Step 2



Dating Ranges of Five Radioactive Elements		
Radioactive Element	Dating Range	
	From	To
carbon-14	from 100 years ago	to 70 000 years ago
potassium 40	from 100 000 years ago	to the earth's beginning
uranium-238	from 10 million years ago	to the earth's beginning
uranium-235	from 10 million years ago	to the earth's beginning
rubidium-87	from 10 million years ago	to the earth's beginning

Table 11-2. Which radioactive element can be used to date materials only a few hundred years old?

Most minerals contain only very small amounts of radioactive elements. And as they decay, the amount decreases. (See Figure 11-15.) If a clam shell is very old and the amount of radioactive carbon in it is so little that it can no longer be measured accurately, then the clam shell cannot be dated by the carbon-14 method. Also, the age cannot be determined if the shell is so young that the amount of decay cannot be measured.

How much radioactive material do most minerals contain?

In order to use the half-life method to obtain an accurate age for the specimen, scientists assume a closed system where there has been no addition or loss of either radioactive elements or the other elements used in the laboratory analysis. If this assumption is not true for a given sample, then the age determination would be wrong. It would be too long or too short, depending on which element was added or lost. Additions or losses can occur by weathering or by the movement of

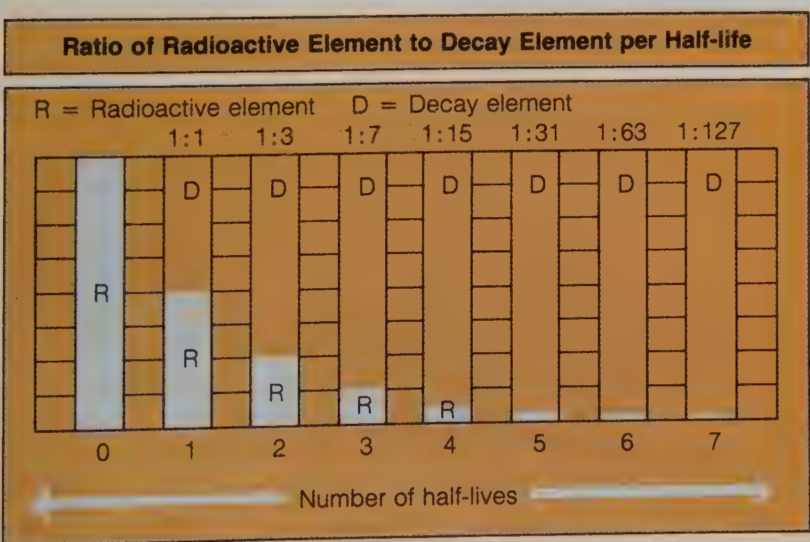


Figure 11-15. If the half-life of a radioactive element is 100 years, and the ratio of radioactive element to decay element in a mineral is 1:63, how old is the mineral? How old would a sample be if the ratio of uranium-238 to lead-206 was 1:1? (Refer to Table 11-1.)

How do scientists minimize errors in age determination?

fluids and gases within the earth. Scientists try to minimize such errors by selecting their samples very carefully.

Different minerals are not affected equally by weathering or by ground fluids and gases. Scientists will therefore use more than one type of mineral and radioactive element in an age analysis of a rock. If all the ages from different minerals in a single rock are the same, it is likely that the assumption of a closed system is valid.

How good are radiometric dates? Half-lives have been determined and verified to be about 98% accurate, which is very good for scientific proof. Laboratory techniques in most cases are equally as good. The logic and mathematics of the techniques are accepted as correct. The dates, then, seem to be very accurate as long as the basic assumptions are valid.

Check yourself

1. What are the basic assumptions for radiometric dating?
2. What are the limitations in obtaining radiometric dates?
3. How can the accuracy of a radiometric date be checked?
4. How good are radiometric dates?
5. Which dating method has the shortest dating range?

The amino acid method

Most ages are determined by using one or more of the radiometric age-dating methods. However, other methods for determining ages are being discovered. These newer methods may provide means of checking or verifying radiometric dates.

One of these newer methods uses certain compounds that form within living organisms. These compounds are called **amino acids.** For dating purposes, amino acids can be divided into two types of mirror-image molecules, those that are right-handed and those that are left-handed. (See Figure 11-16.) While an organism is alive, the molecules are all left-handed. After the organism dies, the left-handed molecules are unstable. They change to right-handed molecules at a rate that can vary with temperature. By determining the ratio of left-handed

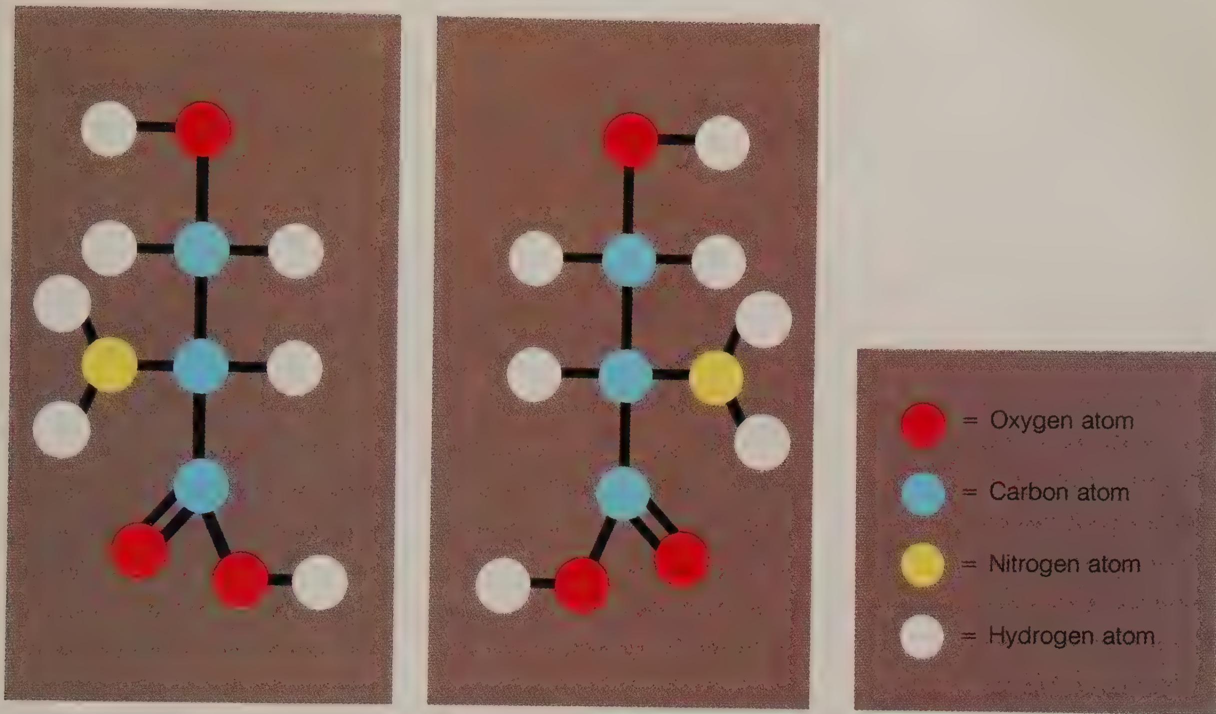


Figure 11-16. These simplified drawings show, in two dimensions, differences between a left-handed molecule (on the left) and a right-handed molecule of the amino acid serine. In reality, such molecules are three-dimensional.

to right-handed molecules and by correcting for temperature changes, the age can be determined. This dating method can be used on some of the same age materials as carbon-14.

The amino acid method of age dating has similarities to the radiometric method of dating and is also based on certain assumptions. Two of the assumptions for amino acid dating are 1) a constant rate of change that cannot be altered by environmental factors other than temperature and 2) a closed system.

Whenever possible, scientists try to make age determinations with different methods. Each method provides a check on the others.

Check yourself

1. Describe the basic principles of amino acid dating.
2. What environmental factor must be known or estimated to use the amino acid method of dating?
3. What types of materials can be dated by using the amino acid method?

Geologic time

What does the age of a metamorphic rock indicate?

What might be indicated by the age of moon rocks and moon soil?

If the basic assumptions are valid, then the date of 3.9 billion years for the rock from Greenland would be more or less correct. But this rock from Greenland is a metamorphic rock. The age of a metamorphic rock is a measure of the age of the minerals that formed during the last stages of metamorphism. How much older was the rock before metamorphism? Indeed, how much older might the earth be?

Most scientists using radiometric age dates put the earth's beginning around 4.6 billion years ago. This age is based on the age of several meteorites and some moon soil. The meteorites probably came from the asteroid belt, a part of the solar system that is believed to have formed at the same time as the earth. As for the moon soil, environmental changes on the moon are unlike those on the earth. Because of the moon's small size, for example, it has no atmosphere to cause chemical weathering. The ages of some moon rocks and moon soil are much older than rocks and soils on the earth and may also reflect the beginning age of the earth and solar system.

How can you get some idea of an age of 3.9 billion or 4.6 billion years? Let one second represent a year. This means that each minute represents 60 years and that an hour represents 3600 years. How many seconds would it take to represent your age?

If each second represents a year, then the oldest rock would be represented by 3.9 billion seconds, which is 123.5 years. The age of the earth would be represented by 4.6 billion seconds, or nearly 146 years.

The age of the earth, or **geologic time**, can also be represented by a physical distance. Look at a ruler with millimeters indicated on it. Let one millimeter represent one year. What distance on the ruler represents your age? What distance on the ruler represents one hundred years?

Using the rate of one millimeter per year, how far do you think the 4.6 billion years of geologic time would stretch? Across an entire state? Halfway across the United States? All the way across the United States? Figure 11-17 shows you just how far 4.6 billion years would stretch, at the ratio of one millimeter per year.

During geologic time, many physical and biological events occurred. Examples of these events are mountain building, erosion, the opening of ocean basins, and the development and extinction of many different organisms. The evidences of these events are rocks and the fossils that the rocks contain.

Figure 11-17. The geologic age of the earth can be represented by a physical distance.

Part of Journey		Distance	Cumulative Distance from Boston
From: Boston, Mass.	To: Providence, Rhode Island	65 million mm	65 million mm
From: Providence	To: Long Island (New York)	160 million mm	225 million mm
From: Long Island	To: Baltimore, Maryland	375 million mm	600 million mm
From: Baltimore	To: Durango, Colorado	2.7 billion mm	3.3 billion mm
From: Durango	To: Lake Mead (Nevada/Arizona)	600 million mm	3.9 billion mm
From: Lake Mead	To: San Francisco Bay (California)	700 million mm	4.6 billion mm

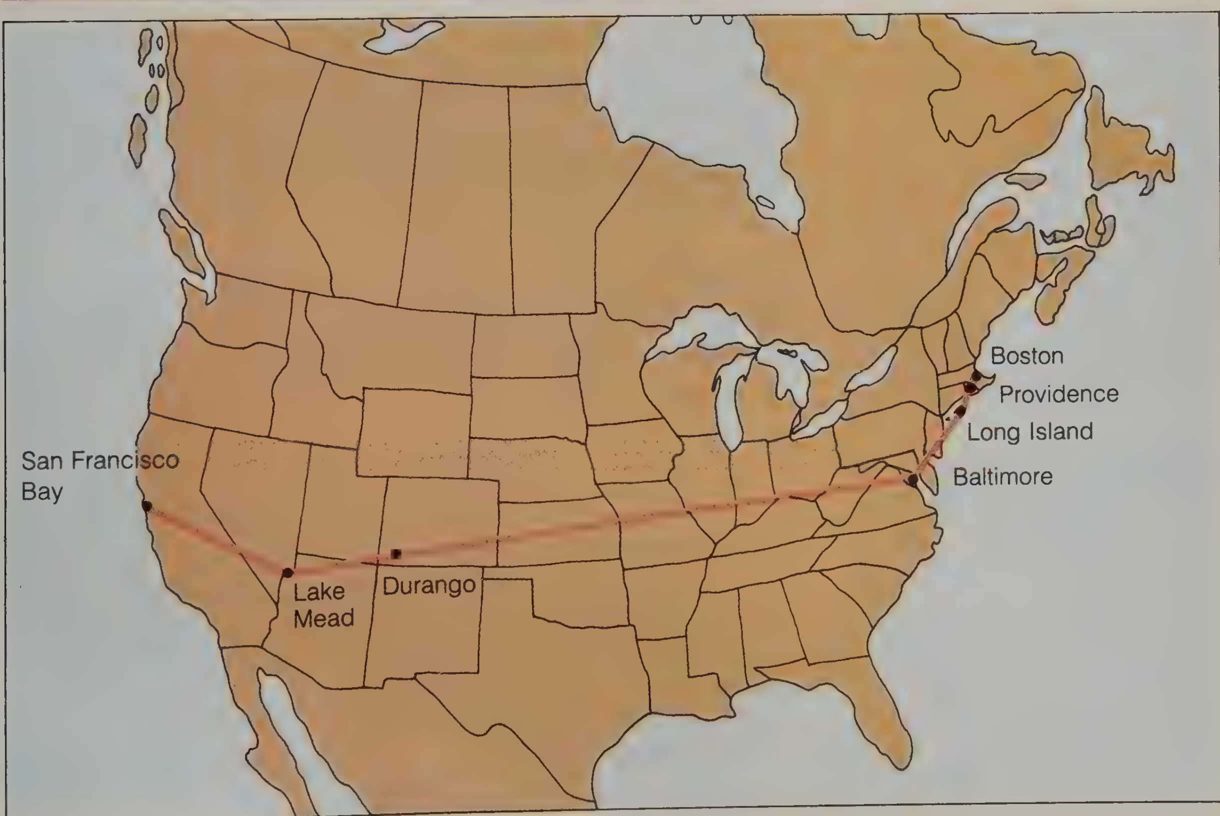


Table 11-3. The earth's history has been divided into four large units of time called eras. What kind of organisms are found in rocks from the Precambrian Era?

The Eras of Geologic Time		
Age	Types of Organisms	Era
present	(most recent life forms) proliferation of birds and mammals	Cenozoic
65 million years ago	(middle life forms) the age of dinosaurs	Mesozoic
255 million years ago	(ancient life forms) first fish, amphibians, reptiles, and shelled ocean organisms	Paleozoic
600 million years ago	(everything before Paleozoic) soft-bodied organisms only	Precambrian
3.3 billion years ago	oldest known fossil	
4.0 billion years ago	oldest known earth rock	
4.6 billion years ago	estimated age of the earth	

Geologic time has been divided into units of time, based on the history of life forms found as fossils in the rocks. The four large units of geologic time are called **eras.** Table 11-3 lists dates and types of organisms for each of the four eras of geologic time.

On the map on the previous page, what location represents the present? What location represents the earth's beginning?

To get some idea of the relative lengths of the geologic eras, look again at the map in Figure 11-17 on page 553. Boston represents the present. From Boston to Providence (65 million mm) represents the Cenozoic Era. From Providence to Long Island (160 million mm) represents the Mesozoic Era. From Long Island to Baltimore (375 million mm) represents the Paleozoic Era. San Francisco Bay represents the earth's beginning, so it requires the entire cross-country distance of 4000 million mm (4 billion mm) from Baltimore to San Francisco Bay to represent just the Precambrian Era.

The Eras and Periods of Geologic Time			
Age	Era	Period	Duration
Present	Cenozoic	Quaternary Tertiary	65 million years
65 million years ago	Mesozoic	Cretaceous Jurassic Triassic	160 million years
225 million years ago	Paleozoic	Permian Carboniferous Pennsylvanian Mississippian Devonian Silurian Ordovician Cambrian	375 million years
600 million years ago 4.6 billion years ago (the earth's beginning)	Precambrian		4 billion years

*The terms *Mississippian* and *Pennsylvanian* are used only in North America. Combined together these periods represent the *Carboniferous Period*, which is the term used throughout the rest of the world.

Table 11-4. Much of the earth's coal was produced during the Carboniferous Period. In which era is the Carboniferous Period located?

Three of the four eras of geologic time are divided into smaller units of time called periods. Table 11-4 lists the eras and periods of geologic time. It also gives radiometric dates for the various units of time.

Check yourself

1. How can scientists justify the use of meteorites and moon soil to determine the age of the earth?
2. List the four eras and the kinds of animals that characterize the eras.
3. Calculate the percentage of earth time for the length of each era. (% earth time = length of each era divided by the age of the earth. Then multiply times 100.)

Activity Approximating Half-Life Decay

Materials

64 equal-size coins

1 small box or plastic container, with lid

Purpose

To simulate half-life decay of radioactive elements.

What to Do

Make a data table similar to the one on this page for ten trials. Complete your data table according to the following directions:

For Columns A and B of your data table.

1. Put all the coins in the bottom of the container, date side facing up.
2. Put the lid on the container.
3. Shake the container.
4. Dump the coins onto a tabletop.
5. Separate the date-side-up coins from the opposite-side-up coins.
6. Count the number of opposite-side-up coins. Record this number in the appropriate box in Column A.
7. Remove the opposite-side-up coins from the tabletop. They will not be used again in this same series of trials.
8. Count the number of date-side-up coins that are remaining. Record this number in the appropriate box in Column B.
9. Put the date-side-up coins back into the container, date side facing up.
10. Repeat steps 2 through 9 five more times, or until there are fewer than two date-side-up coins remaining.

For Column C of your data table.

11. Divide the number in Column A by the total number of coins used for that trial. (For the first trial, the total number used is 64. For any other trial, the total number is the number found in Column B for the preceding trial.) Then multiply the result of the division by 100 to convert it to a percentage.

For Column D of your data table.

12. Divide the number in Column B by the total number of coins used for that trial. Multiply the result by 100 to obtain a percentage.

For Column E of your data table.

13. Divide the number in Column B by 64.

Questions

1. Assuming a perfect half-life decay, what percentage of the original amount would be left after each half-life, to seven half-lives?
2. How do the percentages in Column E of your data table compare with your answer to Question 1?
3. Which column on your data table shows the percentage of date-side-up coins that remain date-side-up with each trial?
4. If the half-life of a radioactive material were one year, how many years would have passed after seven half-lives?

Conclusion

Using your answer to Question 1, how much of the original material would be left unchanged after seven half-lives?

Data Table

	A	B	C	D	E
Trial Number	Total Opposite-side-up Coins per Trial	Total Date-side-up Coins per Trial	% of Opposite-side-up Coins per Trial	% of Date-side-up Coins per Trial	% of Original 64 Date-side-up Coins Left After Each Trial
1					

Check Your Vocabulary

absolute age	half-life
amino acids	radioactive decay
era	radioactivity
geologic time	radiometric dating

Match each term above with the numbered phrase that best describes it.

1. The ability of an element to change spontaneously into a different element by losing or gaining matter from the nucleus of an atom
2. The changing of a radioactive element into a different element
3. A method of age determination that measures radioactive decay of radioactive elements
4. The time it takes for one half of a radioactive material to decay
5. Compounds that form within living organisms and that can be used for age determination of certain earth materials
6. The age of the earth as revealed in its rocks; expressed in eras and periods of time rather than in years
7. One of the four large units of geologic time
8. Age expressed in years

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The ultimate truth of any radiometric date depends on the _?_.
   a) size of the sample
   b) type of substance that the sample is made of
   c) precision and accuracy of lab techniques and equipment
   d) validity of the basic assumptions
2. Of all the nineteenth-century estimates of the earth's age, the most acceptable one was formulated by Lord Kelvin and put an upper limit of _?_ years on the age of the earth.
   a) 9 million c) 100 million
   b) 20 million d) 2.5 billion
3. Lord Kelvin based his calculations of the earth's age on _?_.
   a) the cooling rate of the earth
   b) the amount of salt in the ocean
   c) radioactive measurements
   d) the thickness of sediments
4. If a radioactive element has a half-life of 1 000 000 years, and the ratio of radioactive element to decay element is 1:7, the specimen is _?_ years old.
   a) 3 000 000 c) 8 000 000
   b) 7 000 000 d) 14 000 000
5. The age of the earth is _?_ and it was determined by using _?_.
   a) 3.3 billion/fossils
   b) 4.6 billion/sediment thickness
   c) 3.9 billion/Greenland rocks
   d) 4.6 billion/meteorites

Check Your Understanding

1. How did nineteenth-century scientists determine the age of the earth?
2. How do modern scientists determine the age of the earth?
3. Compare the length of the different eras.
4. What kinds of materials can be dated by radiometric techniques?
5. Explain the absence of any earth rocks representing the first 600 000 years of earth history.

A Parade of Life Forms Section 3

Section 3 of Chapter 11 is divided into five parts:

The fossil record

Precambrian life forms

Paleozoic life forms

Mesozoic life forms

Cenozoic life forms

Figure 11-18. Life forms like *Gorgosaurus* no longer live on the earth. But evidence in the fossil record shows that they are part of the earth's history.

Figure 11-19. This paleontologist is cleaning sandstone away from bones of *Diplodocus* at Dinosaur National Monument, Utah. (The formation is Morrison sandstone.) *Diplodocus* was the longest of all dinosaurs.

4.6 billion years of geologic time extends back far beyond written history. Yet it has been possible for geologists, studying the earth's rocks, to reconstruct life forms from prehistoric times. (A **life form** is the body form that characterizes a fully grown organism.) The results of the geologists' findings make up what can certainly be called a truly amazing parade.

The fossil record

Geologic time has been divided into eras and periods, based on the **fossil record** of life forms found in crustal rocks. Fossils can be either the remains or traces (tracks, burrows, or other evidence of behavior) of organisms that lived on the earth long ago.

The fossil record is the only direct evidence that scientists have of former life forms. Fossils represent an amazing parade of organisms through time. Inferences made from fossils and rocks lead to the reconstruction of ancient environments in which the organisms lived.

Scientists who reconstruct prehistoric life from plant and an-

How does the work of paleontologists affect the parade of organisms?

imal fossils are called **paleontologists** (pay′-lee-on-TOL′-uh-jists). Paleontologists find fossils and make inferences that make the parade of organisms more complete and easier to understand. Like all geologists, paleontologists work within the limitations of the rock record.

One specific limitation that paleontologists find in the rock record is a variable preservation of detail. X-ray photographs of a few trilobites show not only preserved soft body parts but even stomach contents of these prehistoric animals whose fossil record spans the Paleozoic Era. However, most trilobites are preserved only as hard, skeletal fragments. Fossils of *Archaeopteryx* (reconstructed in Figure 11-10 on page 537) show the feathers in great detail. And yet, only three specimens with such detail have ever been found. Some dinosaur remains have been found that include mummified skin. But reconstructing a dinosaur from fossil remains is generally difficult because the bones are usually scattered and broken.

Paleontologists make use of comparison and contrast when

Figure 11-20. How do the forms of prehistoric Irish elk on this and the facing page illustrate the work of a paleontologist?

they make inferences. The structure of an extinct reptile, for example, is either observed directly (in the fossil record) or it is inferred. If inferred, it is based on what is known 1) about living reptiles, 2) about better-known extinct reptiles, and 3) about other organisms living and extinct. Paleontologists use this same principle when making inferences about functions performed by different body parts or ways in which the organism adapted to changes in its environment.

How can scientists make inferences about extinct reptiles for which there are no fossils?

Paleontologists enjoy an excellent fossil record for many types of organisms. Though the record is sparse in certain areas, in other areas it is remarkably complete. Microscopic fossils, for example, are ideal because they are abundant, widespread, and sensitive to environmental change.

The parade of organisms that paleontologists have reconstructed through changing environments and time is admittedly somewhat incomplete because most of the fossils represent sea-dwelling organisms that had hard, mineralized skeletons or shells. As for soft-bodied forms, only a few isolated

Figure 11-21. The fossil bones above are being removed from an outcrop of rocks. Once removed, paleontologists are able to put bones together again, and reconstruct the skeleton of an animal such as on the facing page.

groups of fossil occurrences have been found. Certain worms may leave behind their hard teeth, but it is difficult to reconstruct the size and shape of a worm from its teeth.

Paleontologists realize that their studies also have other limitations. Among these limitations are the following:

1. Not all organisms are easily turned into fossils.

2. Of those organisms that do become fossils, they may not be where scientists can find them. Many fossils are buried far below the earth's surface.

3. Of those fossils that are found, many of the skeletons or shells have been changed by ground water, pressure, and/or heat. Sometimes the change is so great that the fossil loses its identity.

4. As a rule, the older time periods are represented by fewer available rocks because of burial or erosion. Also, older rocks have often been exposed to longer histories of changes due to ground water, pressure, and heat. Therefore, the fossil record of these older rocks is not as good as that of younger rocks.

Working carefully with and from the fossil record, paleontologists have been able to piece together an amazing parade of organisms through time. Put yourself in the reviewing stand and watch the parade go past. As you know, parades come in

different lengths. This parade is very long. It starts 3.3 billion years ago, in the Precambrian Era.

Library research

What is an organism? Give examples of different kinds of organisms.

Check yourself

1. List five limitations that affect the studies of paleontologists.
2. Describe in detail one limitation that affects a paleontologist's studies.
3. On what do paleontologists base inferences about fossils?

Precambrian life forms

The organisms of 3.3 billion years ago are very tiny. Under the microscope, they look like blue-green algae and bacteria. After parading along for 200 million years, some of the blue-green algae form into large mats that grow on top of each other. This strange assortment of bacteria, algae, and algal mats continues on for another 1 billion years. (Similar mats are known to exist today in shallow tide pools in Australia.)

Noticeable changes become more evident. The algal mats are becoming more abundant. During the next 1.2 billion years, colonial bacteria, algal tubes, and cells with a nucleus join the

Activity Making a Fossil Mold

Materials

leaf and/or twig
container with surface large enough for leaf/twig to fit
plaster of Paris
petroleum jelly

Purpose

To learn to distinguish between a fossil mold and a fossil cast.

What to Do

1. When a fossil mold forms, the original fossil is completely dissolved away, and then only a mold of the original shape remains. In this activity, you will make a fossil mold. First, rub a thin layer of petroleum jelly all over the leaf and twig.
2. Grease the inside of your container with petroleum jelly.
3. Mix some plaster of Paris with water and pour it into the container. Leave a space at least 3 cm deep at the top of the container.
4. Place the leaf and twig on the surface of the plaster of Paris before it hardens.
5. After the plaster of Paris hardens, grease the surface of the plaster of Paris with a thin layer of petroleum jelly.
6. Mix more plaster of Paris, and pour it on top of the leaf and twig, to a depth of 3 cm.
7. After the plaster of Paris hardens, remove it from the container and separate the two plaster of Paris blocks, exposing the leaf and twig.
8. Remove the leaf and twig. You now have two molds—one of the upper surface of the leaf and twig, and one of the lower surface.
9. Using modeling clay, see if you can use your mold to make a cast of the fossil. To make a cast, press the modeling clay into one of the molds. Gently peel back the clay and see if any impression from the mold remains on the clay.

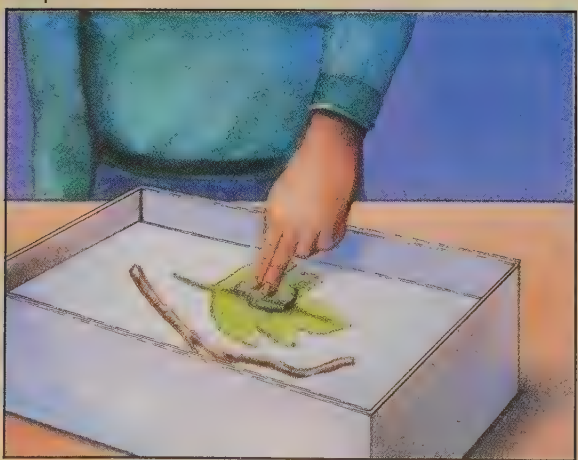
Question

Which looks more like the original leaf or twig—the fossil mold or the fossil cast? Explain.

Conclusion

What is the difference between a fossil mold and a fossil cast?

Step 5



Step 7

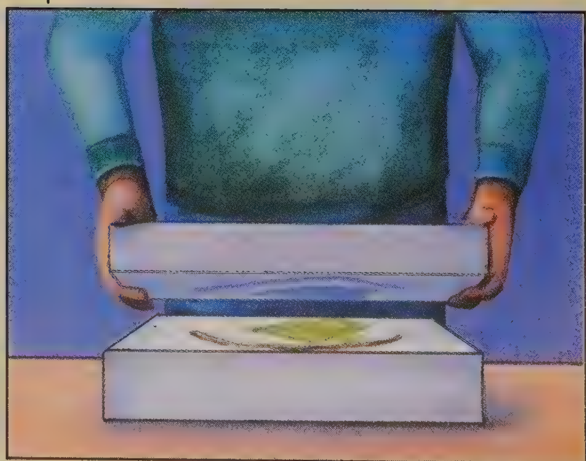


Figure 11-22. Algal mats like these (in present-day Shark Bay, Western Australia) resemble algal mats that formed billions of years ago.

parade. This leads, during the next 200 million years, to some **sexual reproduction** in cells (that is, reproduction that involves the joining together of male and female germ cells).

Mixed into the parade at this time are fungi and threadlike blue-green algae. So far, none of the organisms in the parade has a hard skeleton or shell.

The parade has been very long. 2.6 billion years have gone by so far, and it has been relatively quiet. Then, from southern Australia comes a wondrous group of jellyfish, corals, worms, an echinoderm (i-KĪ′-nuh-derm′), and maybe even a mollusk. All are still entirely soft-bodied. But in that 100 million year interval they are indeed a colorful addition.

Toward the end of the Precambrian Era, much of the land becomes covered with glacial ice, grinding ice and rock against rock in its downhill movement.

This brings the parade to the end of the Precambrian Era and the beginning of the Paleozoic Era.

Figure 11-23. The scallop (left) and snail (right) are mollusks. The starfish (middle) is an echinoderm.

Check yourself

1. How old are the very first fossil organisms?
2. List the types of organisms that are found as fossils in the first 3.8 billion years of Precambrian time. (Remember, the Precambrian is 4 billion years in duration, starting from the earth's formation 4.6 billion years ago.)
3. What types of organisms appear as fossils in the last 100 million years of Precambrian time?

Paleozoic life forms

What marks the boundary between the Precambrian Era and the Paleozoic Era is perhaps the most unique and impressive change in life forms throughout all of earth history. There, like a line of medieval knights wearing armor, are thousands of hard-shelled trilobites from all over the world. These are accompanied by a few scatterings of brachiopods (BRAYK′-ee-uh-podz′), echinoderms, sponges, and sponge-like organisms. All have hard parts.

What caused these organisms to develop hard parts? Were there some chemical changes in the oceans or in the atmosphere? Paleontologists are still pondering these questions!

Figure 11-24. The trilobites and brachiopods of the Paleozoic Era represent a unique change in the life forms that occurred down through the earth's history.

Along with all the wonder and splendor of body armor and support systems, there is a group of organisms from the middle Cambrian period of British Columbia that consists of a large variety of soft-bodied worms. These fossils are preserved as thin carbon films in rocks that were once ocean bottom sediments. Soft-bodied organisms are only rarely preserved as fossils, even though they probably have been abundant since before the beginning of the Paleozoic Era.

As the Ordovician Period of the Paleozoic Era passes by, all the animals mentioned so far are represented in the parade. Even some strange-looking fish are swimming around.

The parade so far has been a very wet parade because all the organisms live in the oceans. Areas of land poke up here and there along the parade route, but there are no plants or animals living much above the splash of the waves. The landscape is barren except for small sea-level fringes of ground-hugging algae and tiny animals, both struggling against the elements for survival. Even the air is barren, for there are no flying insects.

Silurian seas were populated with diverse armored fishes. Some were very fierce in appearance. As the parade reaches the late Silurian Period (about 425 million years ago), the first land plants, which are very small, start to appear. Scorpion-like arachnids, the first fossil land animals, are quick to follow. Trilobites are on the decline.

Library research

What is an arachnid? How does it differ from an insect?

What are conditions on the land like during the Ordovician Period?

Figure 11-25. Scorpions go way back in the rock record. Some forms still live on the earth.

When did amphibians, the first land vertebrates, appear?

Devonian seas, like Silurian seas, contain some very remarkable predatory fishes, both sharks and bony fish. By the end of the Devonian Period, the land takes on a new appearance with swamps and forests. Also, late in the Devonian Period there is another type of movement on the land—amphibians! Land vertebrates have joined the parade.

Invasion of the land is by a select group of organisms, and it is not an easy transition. Life developed in the oceans where water keeps organisms moist and where water provides support and protection. A floater like the jellyfish cannot survive on land. Because the jellyfish cannot support itself on dry land, it cannot move, breathe, or eat. And it will finally dry up. Land

Figure 11-26. Some very remarkable predatory fishes lived in the Devonian seas.

dwellers in the Devonian Period had developed skeletons that gave support. They also developed protection from drying up and a way to use oxygen from air rather than from water.

Why is a skeleton needed by a land dweller?

During the Mississippian and Pennsylvanian Periods, swampland forests covered much of the land. The plants that grew in these swamps died, were buried, and changed to coal (a form of carbon) in great amounts. (Modern relatives of these swamp trees can be found as small forest and pondside forms.) Also during this time, called the Carboniferous time, dragonflies, cockroaches, and other winged insects are abundant. It is at this time that the first reptiles, which are amphibian-like, appear in the parade.

Figure 11-27. By the end of the Devonian Period, swamps and forests are found on the land.

Figure 11-28. By the Permian Period, many different types of animals are found on the land.

The Paleozoic Era ends in the Permian Period. By this time, the land has become forested with many types of trees although none of them is a flowering tree. Land animals are abundant, with many different types of amphibians, reptiles, and insects. Some dragonflies are as big as present-day blackbirds. Some of the reptiles have features like the spiny fin on *Dimetrodon,* which aids in the control of body temperature.

The dominant sea dwellers are no longer trilobites as in the early Paleozoic Era. Seas in the late Paleozoic Era contain many fish and brachiopods.

Gradually the amount of land increases. Populations in the oceans are changing, sometimes gradually and sometimes rather abruptly. Some kinds of organisms that pass by are never seen again. They become extinct. Other organisms persist. If these persistent organisms still have living representatives today, they are referred to as **living fossils.**

What is a living fossil?

Then another abrupt change occurs. Most of the land and ocean dwellers are seen for the last time. Land organisms like the lycopod trees and seed fern trees become **extinct,** which means they die out without leaving any descendants on the earth. Major groups of all animals, including trilobites and many brachiopods, become extinct. Only the fish show little change.

This major time of extinction marks the end of the Paleozoic Era and the beginning of the Mesozoic Era. It occurred at a time when the oceans had receded and much of the land was dry. Some fossil tracks have been found in Permian rocks formed from desert deposits.

What happened to the oceans at the end of the Paleozoic Era?

During the Paleozoic Era, the continental masses of the earth's crust were assembled into one large landmass, or a supercontinent. Following the Permian Period, the continental masses began to separate. During the Mesozoic Era, we witness the continued breakup of supercontinents into the ones we know today.

Check yourself

1. What spectacular development in organisms marks the beginning of the Paleozoic Era?
2. What were the first types of land vertebrates, and when did they appear?
3. Describe the history of land plants during the Paleozoic Era.
4. What types of events end the Paleozoic Era?

Mesozoic life forms

The parade changes character in the early Mesozoic Era because of all the disappearances at the end of the Paleozoic Era. Only persistent organisms continue on. Although there are only a few different types of organisms, they are present in great numbers. Then begins a succession of many new kinds of animals, some of which come and go rapidly.

Some of the mollusks have worldwide distribution in the oceans but live only a short time before becoming extinct. It is as though they line themselves up from one side of the watery parade to the other. Each line is a new and different type, never to be seen again after passing by. These particular mollusks are a type of cephalopod (SEF′-uh-luh-pod′), distant relatives of modern squid. One day, these cephalopods will provide excellent index fossils for scientists.

Figure 11-29. This Boreal squid is a member of the class of animals called cephalopods.

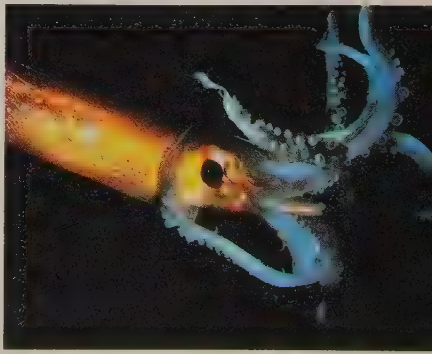


Figure 11–30. Dinosaurs were the largest dwellers ever to populate the land. During what geologic period do they disappear from the land?

Land masses are still populated by various insects and plants. Many of them survived the changes at the end of the Paleozoic Era.

New kinds of land vertebrates keep appearing as the parade continues. Chicken-size and dog-size dinosaurs and small rodent-like mammals come along late in the Triassic Period. By the middle of the Jurassic Period, the dinosaurs become the largest dwellers ever to populate the land. Along with the land giants of the Jurassic Period are the first true birds. Except for feathers and proportionally larger brains, the first birds have teeth and are structurally similar to small dinosaurs.

Library research

What is a vertebrate? How does it differ from an invertebrate? Give examples.

Mixed in with the birds and giant dinosaurs are the first flowering trees. Because the climate of the whole earth is quite warm, the flowering trees spread far toward the North and South Poles.

Where the large plant-eating dinosaurs roam, there are moderate-sized meat-eating dinosaurs in pursuit. As the parade passes into the Cretaceous Period, the plant eaters get smaller and the meat eaters get bigger. Any mammals in this part of the parade are small and very primitive.

In the warmer, shallower parts of the oceans, corals and clams form reefs. The land becomes greatly flooded by the oceans, and only small land masses are seen.

Then, late in the Cretaceous Period, the land masses begin to rise again. Suddenly, the reef-forming clams disappear. The group of cephalopods that will be such good index fossils disappear. Most swimming reptiles disappear. The dinosaurs disappear. Many types of organisms also disappear, including microscopic ocean-drifting forms.

The Cretaceous Period comes at the end of what geologic era?

Another major time of extinction changes the character of the parade. And the Mesozoic Era ends.

Check yourself

1. What types of changes occurred in land-dwelling animals during the Mesozoic Era?
2. How did plants change during the Mesozoic Era?
3. What events in life forms occurred at the end of the Mesozoic Era?

Cenozoic life forms

The change in life forms at the beginning of the Tertiary Period is accompanied by a change in temperature that affects the distribution of flowering trees. As the earth's climates become cooler, cone-bearing evergreens become more abundant in the colder areas.

Marine organisms increase in numbers and kind. Fish take on a modern aspect. And mammals, which have been in the parade for some time, start to become more abundant. In many cases, the mammals are also increasing in size. Progressing through the Tertiary Period, the mammals begin to look more and more familiar. By the end of the Tertiary Period, hominid (human-like) forms appear.

The Tertiary Period passes, and we now see the Quaternary Period, which is divided into two epochs (Pleistocene and Recent). During the Pleistocene Epoch, glaciers covered much of the Northern Hemisphere. The glaciers grew and melted sev-

Figure 11-31. Modern human forms appeared during the Pleistocene Epoch. In what geologic period is the Pleistocene Epoch found?

eral times, causing changes in the land environment and in sea level and water temperature. Although land dwellers were affected significantly, organisms living in the sea were relatively unaffected.

How did Pleistocene glaciers affect land dwellers and sea dwellers?

As the parade progresses through Pleistocene time, modern human forms appear. Gradually the entire parade becomes a scene that catches up to us in time. We must now leave the reviewing stand and take our place in the parade.

Check yourself

1. The Cenozoic has been called the age of mammals. What types of changes make the Cenozoic the age of mammals?
2. What parts of the environment were affected most by the Pleistocene ice age?
3. How did the earth's climate change at the very beginning of the Tertiary Period?

Activity Distinguishing Fossils and Inferring Ancient Environments

Materials

clam shell
fossil brachiopod
crab carapace
trilobite
wood
carbonized wood
petrified wood
casts and/or molds of fossils

Purpose

To distinguish different types of fossils and infer their original environments

What to Do

1. Divide the specimens into two sets, fossils and nonfossils.
2. Divide the fossils into sets, based on similarities and differences that you observe. Use any possible features that you can see or test (color, mineral or tissue composition, hardness, density, and so forth).
3. For each set and/or specimen, write down the differences.

Questions

1. Which of the fossil specimens might contain the original skeletal material?
2. Which of the fossil specimens probably represent material that has been replaced by some mineral? How can you tell?
3. What environmental differences could cause the differences between the two different kinds of fossilized wood?
4. Which specimens are casts? Which are molds? How can you tell the difference?

Conclusion

How did you decide which specimens were fossils and which were not? What general types of environmental differences could you infer about your fossils?

Going Further

From the types of fossils and the types of sediments or rock particles, what can you infer about the specific ancient environment in which each of your fossil specimens formed? Use the data table below for reference.

Environment	Depth of Water	Temperature of Water	Type of Sediment or Rock Particle	Type of Fossil
1. carbonate bank	shallow	warm	lime mud	algae, mollusks
2. coral reef	shallow	warm	broken skeletal fragments	corals, bryozoans, sea fans, shells
3. river delta	shallow	warm or cool	sand and silt	some mollusks or brachiopods
4. sand beach	shallow to above water	warm to cold	sand	shells and shell fragments
5. continental shelf	to 350 m deep	warm to cold	sand and silt	burrowing shells
6. deep sea basin	deep ocean	cold	silt and clay	burrowing organisms
7. volcanic area	all depths	warm to cold	volcanic rocks and fragments	usually none
8. swamp or marsh	very shallow	warm to cold	mud (sand, silt, and clay)	plants and either freshwater or saltwater animals

Section 3 Review Chapter 11

Check Your Vocabulary

extinct	living fossils
fossil record	paleontologist
life form	sexual reproduction

Match each term above with the numbered phrase that best describes it.

1. The record of former life forms as preserved in the earth's rocks
2. A scientist who reconstructs prehistoric life from plant and animal fossils that are found in the rock record
3. Reproduction that involves the joining together of male and female germ cells
4. Fossils of organisms that have representatives still living today
5. Died out completely, without leaving any descendants on the earth
6. The body form that characterizes a fully grown organism

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The oldest known fossils are _?_.
   a) trilobites and brachiopods
   b) algae and bacteria
   c) fungi and algae
   d) worms and jellyfish
2. The oldest known fossils are _?_ years old.
   a) 4.6 billion c) 3.3 billion
   b) 3.9 billion d) 1.2 billion
3. The beginning of the Paleozoic is marked by _?_.
   a) organisms with hard parts
   b) extensive glacial deposits
   c) fish and fungi
   d) a great number of desert deposits
4. The first reptiles occurred during the _?_ Period.
   a) Ordovician
   b) Carboniferous
   c) Triassic
   d) Tertiary
5. All _?_ became extinct at the end of the Paleozoic Era.
   a) dinosaurs c) flowering plants
   b) fish d) trilobites

Check Your Understanding

1. What is the nature of the fossil record?
2. Some organisms are more easily fossilized than others. What characteristics of the organisms would favor fossilization?
3. What types of events mark the boundaries between the eras? Be specific.
4. How would you characterize the life forms of each era?
5. Describe the progression of vertebrates through time, listing the periods and the types of vertebrates.

Chapter 11 Review

Concept Summary

An **assumption** is the taking for granted that a certain process or scientific law remains constant through time and place.

- ☐ Assumptions are necessary in science.
- ☐ Uniformitarianism is the basic assumption of all sciences.
- ☐ Scientific principles and laws are merely well accepted assumptions.
- ☐ The principles of original horizontality, superposition, and faunal succession are used in interpreting the rock record.

Theories are working statements intended to be tested, modified, added to, or replaced.

- ☐ Darwin's theory of evolution appears valid in a limited number of cases.
- ☐ Other theories of evolution are proving to be useful in complementing Darwin's theory.
- ☐ Data from nature is the raw material for testing scientific theories.

The **rock record** is the history of the earth as recorded in its crustal rocks.

Absolute age determinations estimate the age of the earth in years. Such age determinations have been made in many ways.

- ☐ Nineteenth-century estimates included sediment thickness, salt content of oceans, life spans of fossils, and the cooling rate of the earth.
- ☐ Radiometric dating assumes a constant decay rate and a closed system.
- ☐ Radiometric dates showed the earth to be 4.6 billion years old, much older than the nineteenth-century estimates.

Geologic time is a method of age determination that dates the earth's history not by years but by eras and periods of time.

The **fossil record** is the record of former life forms as preserved in the earth's rocks.

- ☐ The fossil record spans 3.3 billion years of the earth's 4.6 billion year age.
- ☐ The most common fossils are of those organisms that had hard parts like shells or bones.
- ☐ The Precambrian Era contains fossils of soft-bodied organisms only. For example, algae, bacteria, worms, and jellyfish.
- ☐ The Paleozoic Era starts with organisms having hard shells. For example, trilobites and brachiopods.
- ☐ All major groups of organisms are represented by fossils before the end of Ordovician time. (Vertebrates would be a major group, for example.)
- ☐ The ends of the eras are marked by major times of extinction.
- ☐ The Mesozoic Era was the age of the dinosaurs, the first true birds, and the first flowering tree.
- ☐ The Cenozoic Era is marked by the expansion of mammals and the development of modern fish.

Putting It All Together

1. How does uniformitarianism apply to geology?
2. How would the law of faunal succession help in evaluating theories of evolution?
3. What are the main scientific objections to applying Darwin's theory of evolution to all organisms?
4. How are formations of rock used in studying earth history?
5. What kinds of information about earth history can be obtained from unconformities?
6. Explain in detail the assumptions and principles of radiometric dating.
7. How can carbon-14 dates be checked?
8. List the periods of geologic time, and opposite each period indicate a new or abundant life form or major event of earth history that occurred then.

9. Add to your list of periods the names of the eras and the absolute ages of the boundaries between eras.
10. What aspects of the environment make it difficult for soft-bodied organisms to be preserved as fossils?

Apply Your Knowledge

1. What types of rocks would you most likely find fossils in?
2. What technologic or scientific changes would have to occur in order to obtain reliable radiometric dates in the 70 000 to 100 000 year range?
3. What geologic processes in your community are adding to the rock record? Be specific about locations.
4. What geologic processes in your community are contributing to a future unconformity? Be specific.
5. If all written history became destroyed and lost, how would people 20 000 years from now reconstruct the twentieth-century environment?

Find Out on Your Own

1. From a library, obtain geologic maps and descriptions of your area. Describe the geologic history of your area, including environments and unconformities.
2. Collect rocks (or use the rocks collected for Chapter 2), label them, and describe the type of ancient environment that each of them might represent.
3. Collect fossils and determine which of them are marine or non-marine. Use library sources to help you. Also, label them according to type and relative age (Cambrian, Ordovician, . . .).

Reading Further

Colbert, Edwin H. *The Year of the Dinosaur.* New York: Charles Scribner's Sons, 1977.

The description of a year in the life of a brontosaurus, told by an expert paleontologist. An interesting way to recreate a year from the distant past. Involves the reader in an active and imaginative way.

Editors of Time-Life Books. *Life Before Man.* New York: Time-Life Books, 1972.

Excellent photographs of fossils, showing clearly the precision of detail that is sometimes available in the fossil record. Also includes diagrams, photographs, and text for more theoretical aspects of evolution, behavior, communication, and various life processes.

Freedman, Russell. *They Lived with the Dinosaurs.* New York: Holiday House, 1980.

An interesting presentation of fossils and their living relatives.

Ricciuti, Edward R. *Older Than the Dinosaurs: The Origin and Rise of the Mammals.* New York: Crowell, 1980.

Describes the evolution of mammals and the rise and fall of the dinosaurs.

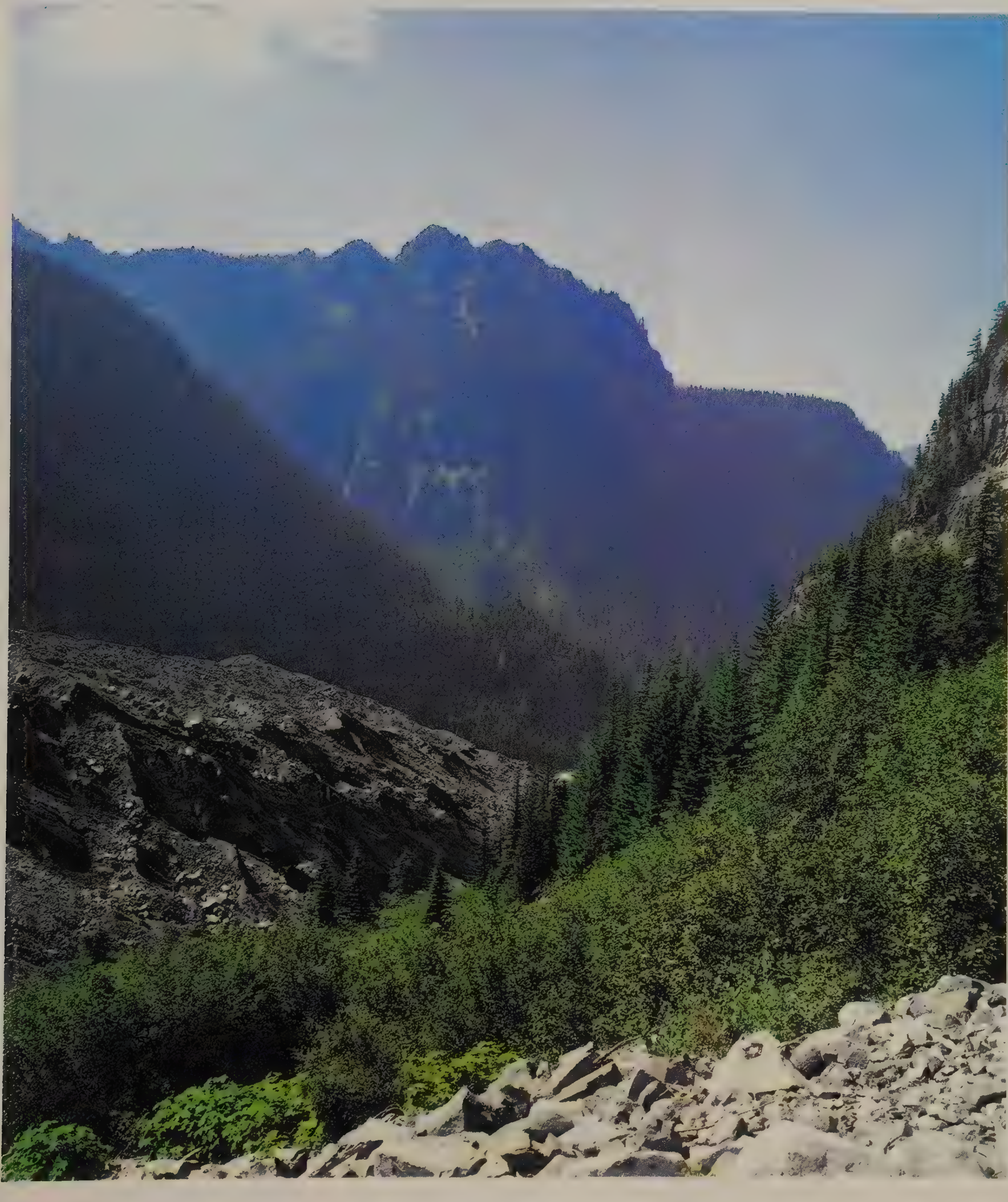
Rydell, Wendy. *Discovering Fossils.* Mahwah, NJ: Troll, 1984.

An excellent book with clear explanations of what a fossil is and how old the earth is. Describes some of the great fossil discoveries, such as the woolly mammoth in Siberia. Tells how you can hunt fossils.

Tweedie, Michael. *The World of Dinosaurs.* New York: William Morrow and Company, Inc., 1977.

Clear photographs of fossil bones and other evidence of earth history. Large, colored drawings that recreate these animals and their habitats, based on evidence in the rock record. Explanatory text and captions.

Chapter 12 An Environmental Concern



Preserving the Land

"Preserving the Land" is divided into three parts:

Taking from the land

Heaping up upon the land

A suitable environment for life

Figure 12-1. Waterfalls like the Sahalie Falls of Oregon add excitement and beauty to the earth's landscapes.

Figure 12-Opener (on the preceding page). Much evidence of weathering, erosion, and deposition can be seen in this area (Carbon Glacier) of Mount Rainier National Park, Washington.

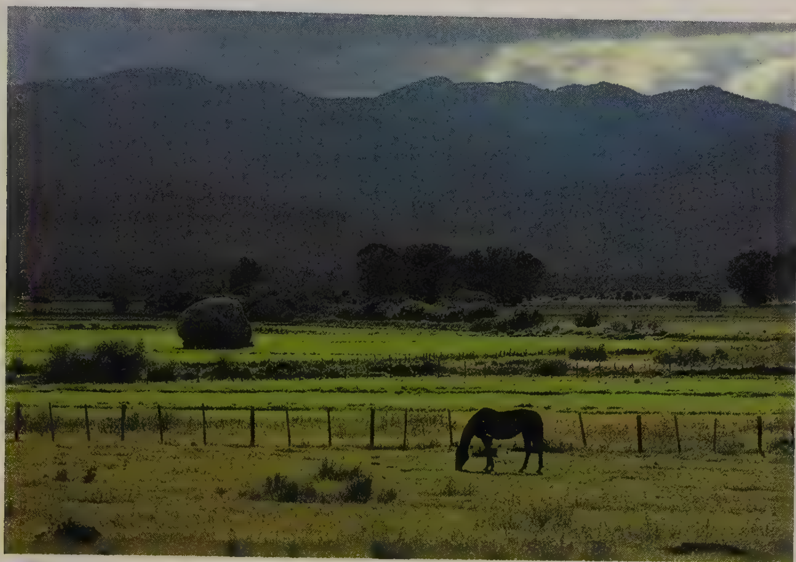


Figure 12-2. What natural earth processes produced this farmland in Jackson, Wyoming?

People are putting ever greater demands upon the earth's materials. Many resources that we take from the land are *nonrenewable resources*. Once used up these can never be replaced. Oil is a nonrenewable resource. *Renewable resources* such as wood can be replaced, but are often taken too rapidly.

Taking from the land

Huge areas of the earth's surface have been laid waste because of overuse or misuse. In the past, it may have been possible to merely move on to another location, ignoring the damage that had been done to the earth. Today, however, it is becoming increasingly clear that the earth's land is limited.

In addition to urban development and suburban sprawl, three human activities have had particularly marked effects our land and resources. Those activities are farming, lumbering, and mining.

Farming. The people of the world need food to live. Part of the earth's surface will, therefore, always be needed to obtain food. (Farmland is necessary for raising grains, fruits, and vegetables. Pasture land is needed by grazing animals.) In their search for food, however, it is possible for people to abuse the land and render it useless.

Our Science Heritage

Improving the Environment

Pollution is not new. From the mummy of a woman who died in China more than 3000 years ago, scientists were able to determine that she had a lung condition known as pulmonary emphysema. In addition, her lungs contained deposits of various metallic elements, carbon, and silicon dust. Researchers believe that the carbon deposits indicate the environment was polluted from "the smoke that came with the burning of wood, animal carcasses, and other combustible material."

Pollution may not be new. That does not mean nothing can be done about it. Much, in fact, has been done. But much remains to be done.

In the area of technology, pollution-controlling devices have been invented and are being used to reduce the amount of the pollutants that are introduced into the environment. The numbers, types, and uses of such devices change rapidly. Only a newspaper, magazine, or almanac can keep up with the latest technological advances.

The most important advances, however, might have been those that have taken place in the area of public awareness. Ten or fifteen years ago, far fewer people were even aware of the problems. Such terms as *habitat* and *food chain* were unfamiliar. And many warnings went unheeded.

The condition of the environment has now become a matter of public concern. And more and more individuals are beginning to realize that each of us shares the responsibility for maintaining the earth as a life-supporting planet.

What are two harmful effects of the heavy use of ground water?

One area of abuse has to do with the indiscriminate removal of ground water. Great technological advances make it possible to pump water from very deep underground. Heavy use of ground water to irrigate arid land has lead to land subsidence, where the underlying geologic formations have been so weakened that the land has settled 10 m or more.

In addition to land subsidence, indiscriminate removal of ground water can also introduce dissolved salts from the sea. Near bodies of salt water, heavy use of ground water can cause salt water to infiltrate the underground water supply.

Figure 12-3. The plant cover of this South African field can provide food for a limited amount of grazing animals and, at the same time, continue to replenish itself.

Another area of abuse has to do with overgrazing and overproducing. In those instances, the soil can be drained of nutrients needed by plants for life. Huge areas of land can lose their vegetation and even their soil cover. Such exposed soil is likely to be lost through erosion by water or wind.

Figure 12-4. This area of Etosha National Park, South West Africa, shows the effects of overgrazing.

Is land a resource?

A lesson to be learned is that better use must be made of land as a resource. There must be greater planning and control in the use of the land for farming and for raising cattle. Greater care must also be taken in how the water supply is used. Limits must be placed on water use and there must be more water recycling.

Lumbering. As the need for lumber, for paper, and for paper products increased, millions of acres of forest land have been stripped and erosion of the soil became extensive. In the past, little effort at conservation of this renewable re-

Figure 12-5. Near Olympic National Park, Washington, an area of forest has been clear cut of trees. To prevent soil erosion and to restore the forest cover, the clear-cut area will be replanted with seedling trees.

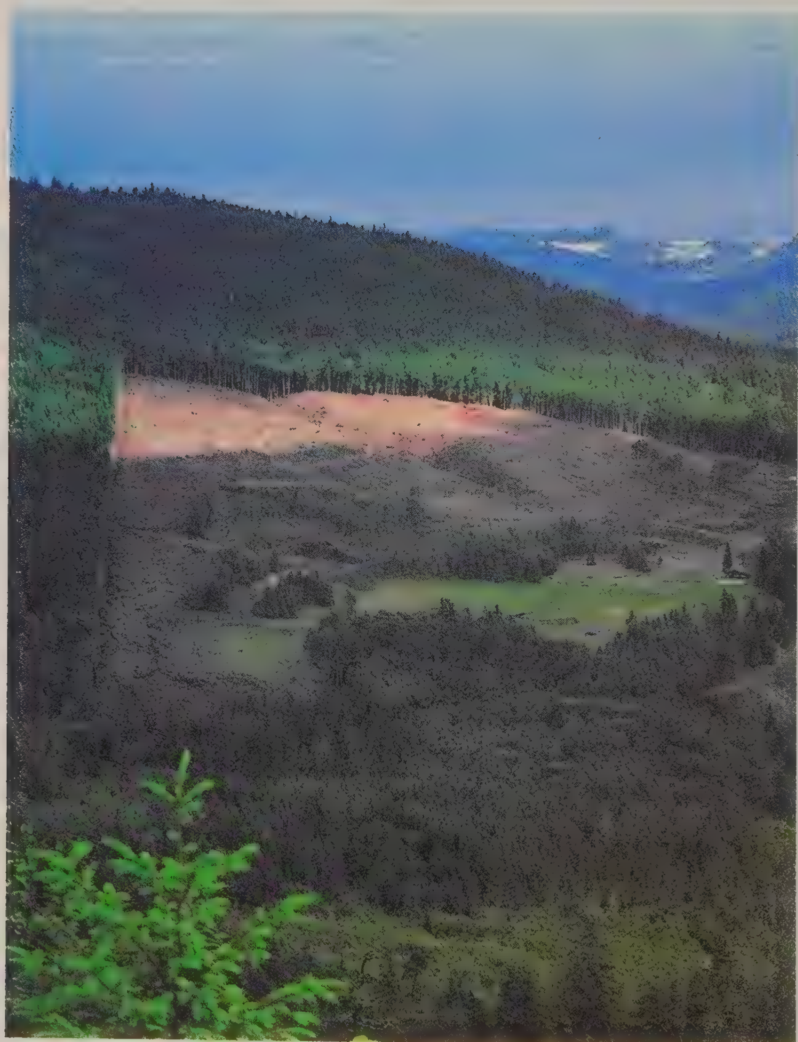


Figure 12-6. These rows of seedling ponderosa pines will be used to replant clear-cut forest areas. Ponderosa pines are valued for their timber.

source was made because it was felt that the supply of forest land was unlimited. Today, better practices are being followed. Removing trees from forests today is a much more selective process. As trees are removed, new seedlings are planted. Such a program of **reforestation** (ree′-far-ist-AY′-shin) has two positive effects: 1) the soil in forest lands is preserved, and 2) a future supply of trees for wood and paper products is assured.

Figure 12-7. These workers are getting ready to plant seedling trees on a timber farm on the Indonesian island of Borneo.

Mining. Besides serving as the major source of food products, wood products, and underground water, the land also provides valuable minerals. During the early part of this century, vast areas of land were defaced as people searched for and found extensive mineral deposits. The mining of nonrenewable ores of iron, lead, aluminum, and other metals left scarred landscapes across large areas of the earth's surface.

Sometimes, instead of digging underground, minerals were obtained from **strip mines,** which are huge open pits dug near the surface of the ground. Large strip mines have been dug in the Mesabi Range (muh-SAH′-bee), a mountain range in Minnesota that was extremely rich in iron ores. And in Bingham Canyon, Utah, the world's largest strip mine was dug to obtain copper ore. Surface **quarries,** from which building stone was removed, are also examples of strip mines.

Figure 12-8. This area, in the Butchart Gardens (22.5 km north of Victoria, British Columbia), shows how an abandoned rock quarry was restored to a landscape of beauty.

In the past, once the resources in a mine became depleted, little effort was made to restore the landscape to its original condition. Huge pits were left in the ground, which caused more erosion in the surrounding area.

Today, there is evidence of a changing attitude toward the earth's minerals. First of all, there is an increasing awareness that the earth's mineral resources are not unlimited, as was formerly thought. And secondly, efforts are being made to restore mined-out areas of the earth's surface to a condition more closely resembling their natural state.

Check yourself

1. Why are farming, lumbering, and mining necessary activities?
2. How has each (farming, lumbering, mining) affected the earth's surface? In each case, how can the effects be offset by some kind of restoration?

Heaping up upon the land

It has often been said that we live in a "throw away society." By this it is meant that we throw things away after we've used them only once or perhaps a few times. For example, many of the beverages we drink (e.g. milk, soda, juice, etc.) come in disposable containers. Once used, these containers are thrown away. But prior to about thirty years ago, many of these same beverages were packaged in reusable glass containers that were used again and again, as deposit bottles are today.

Are reusable glass containers in use at the present time?

The same is true for other items. In the past, broken radios, toasters, and other small appliances were repaired. Today, it is often cheaper to buy a new item than to pay the cost of repairing the broken one. Such practices create huge amounts of discarded materials.

How much "garbage" does accumulate? Suppose for each member of your family 0.5 kg of garbage is disposed of each day. This would include food scraps, empty containers, newspapers, cartons, broken appliances, etc. Now suppose you live in a medium-size city of about 100 000 people. This means that each day 50 000 kg of garbage must be disposed of. For one year, this would amount to 18.25 million kilograms (or 18.25 thousand metric tons). Add to this all the waste disposed of by industrial and retail operations, abandoned automobiles and trucks, and the total amount can probably be doubled.

Library research

How many tons of paper, glass, metals, food scraps, and other waste materials were generated in the last year of the most recent estimate you can find? How does this compare with twenty years ago and with the population growth since then?

To give you an idea just how much solid waste this is, consider a compact-size automobile to weigh about one metric ton. This means that for our model city the annual solid waste disposal is equal in mass to about 18 000 compact automobiles. That is a lot of garbage!

What do we do with all that garbage? A small amount, particularly from industrial and retail operations, is **recycled.** Some cities and towns have also established recycling programs for such materials as glass, aluminum, and old newspapers. Newspaper, glass, and metal can be broken down and used again. But the process is costly.

At the present time, most solid waste is not being recycled. Most solid waste is **incinerated** (in-SIN′-uh-rayt′-id), or completely burnt up. Since much of this solid waste will burn, the total mass of solid waste is greatly reduced after incineration.

Activity Considering the Economics of Recycling

Materials

data table on this page

Purpose

To see if a recycling program can pay for the cost of waste disposal and provide an affordable source of raw materials.

What to Do

1. Using the data in Part A of the data table, calculate on a piece of paper the amount of money received for each material and the total for all recovered materials.
2. Using the data in Part B, calculate the cost for disposal and for land. Add those two costs to determine the total cost of waste disposal.

Questions

1. Can the material recovered pay for the cost of disposal? Give evidence for your conclusion.
2. The total disposed in Part A does not equal the total disposed in Part B. What do you think accounts for the difference?

Conclusion

What other factors, if any, should be considered when discussing the economics of a recycling program?

Data Table			
A. Material Recovery Income	Material	Total Disposed (tons)	Payment Rate ($ per ton)
	paper	50 000 000	5
	glass	15 000 000	12
	scrap iron	12 000 000	20
	aluminum	1 500 000	400
B. Cost of Waste Disposal	Item	Total Disposed (tons)	Disposal Cost ($ per ton)
	disposal	150 000 000	43
	land (for dumping)	150 000 000	6

Figure 12-9. How much solid waste must a city of 100 000 dispose of in a year if each person disposes of 0.5 kg of garbage per day?

Many cities and towns burn their garbage in incinerators. But this is not an ideal solution because some products contribute to air pollution when they are burned.

Some waste products can be buried in a **landfill,** a large pit in the ground which is filled with layer upon layer of garbage. The heat and pressure of the overlying layers cause biodegradable materials to decompose. Cans made of iron and tin also decompose through the process of oxidation.

Some materials, however, present more of a problem. Many of the cans used today are made of aluminum. Aluminum oxidizes much more slowly than iron, but eventually it too will break down. Plastic and rubber products are also a problem because they do not decompose.

In a large city, a landfill area several kilometers in diameter may be filled in less than twenty years. Eventually, the mounds

of garbage become too high to permit additional dumping. New sites must be found.

Some coastal cities attempted to resolve the problem by carting the garbage out into the ocean in barges. There the garbage was dumped. Unfortunately, studies have shown that this causes more pollution than was first expected.

Great advances have been made in the incineration of solid wastes. For one, modern incinerators cause much less air pollution than their predecessors. These incinerators operate at much higher temperatures than their predecessors. At these higher temperatures any hazardous materials that were formerly released into the atmosphere are broken down.

Check yourself

1. What are three ways in which waste products and materials are disposed of?
2. Describe the different things that happen to waste materials buried in a landfill area.

Library research

For the most recent year you can find, how much waste material was disposed of in landfills? in incinerators? in the ocean? What kinds of materials were disposed of in each way?

A suitable environment for life

In the past 150 years, great technological advances have resulted in an array of products unthought of just a short time ago. Everywhere you look, you will see examples of those items. But every one of those items has cost something—not only in money but also in the supply of earth materials.

In recent years, it has become increasingly evident that there are limits even to the earth's resources. There is just so much to go around. And once those supplies are depleted, people will be forced to find and use something else.

The oil crisis of the early 1970s forced industrialized nations to realize how much of their economies was based on cheap and plentiful supplies of oil. For the first time, people came to recognize in a forceful way that supplies of energy are not limitless. In some places, gasoline was rationed, and people had to wait in long lines to purchase gasoline when it was available.

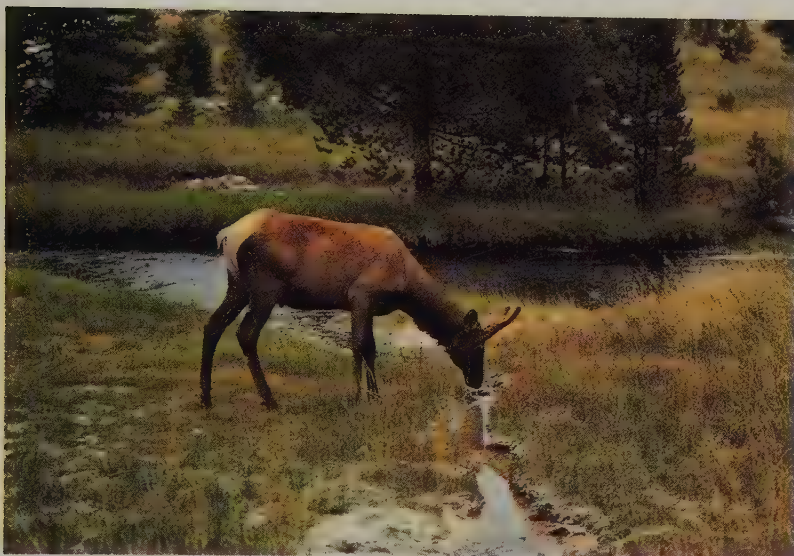


Figure 12-10. Abundant water and over 2.2 million acres of protected land provide an environment for elk and many other varieties of wildlife within the boundaries of Yellowstone National Park.

Even after the crisis was over, the price of gasoline remained much higher than before.

A lesson had been learned. Greater efforts would have to be made to find other sources of energy. When energy was cheap, there was little incentive to develop new sources of energy. Now, however, alternate sources such as solar energy are being explored.

Because of the energy crunch, people have come to realize that other of the earth's resources are also limited. Governments can have a powerful effect by acquiring land and protecting it from development. In that way, the earth's natural processes will be allowed to continue. As an example, consider the government acquisition of wetlands.

Wetlands are coastal and freshwater swamps. They serve as breeding grounds for thousands of plant and animal species. They also help to filter pollutants from surface water. Many of these wetlands are located near heavily populated areas. In many cases, this makes the land itself very valuable.

Almost a third of the wetlands in the United States have been filled in and converted for other use. Houses, factories, airports, and parking lots have been built over land that was formerly wetlands. But now, through the efforts of local, state, and federal agencies, attempts are being made to stop this process.

Library research

Since 1900, how much open land has been converted to other uses? What are the uses? What is the outlook for the future?

Careers Range Manager / Chemical Laboratory Technician

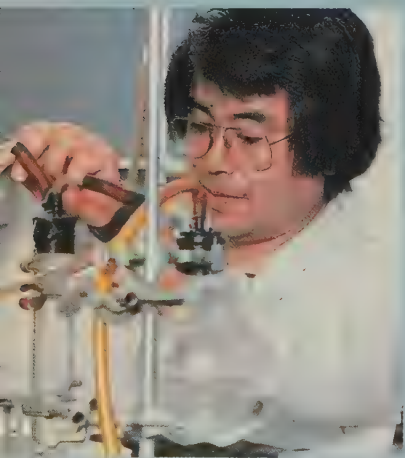
Range managers spend much of their time on the range.

Range Manager Rangelands cover over 2 billion acres in North America. They have important economic uses such as ranching and mining. They also serve as recreational areas and provide a habitat for wildlife.

Range managers work to increase the productivity of the land while protecting the environment. They help ranchers increase cattle or sheep production, and they reclaim areas that have been damaged by strip-mining. Range managers spend much of their time on the range. They also do a certain amount of office work, including report-writing. They frequently work with other people.

Range managers must have an understanding of biology, chemistry, physics, math, and communication skills. Knowledge of forestry, hydrology, and fish and wildlife management is desirable, as is good physical condition.

The best preparation for this career is a bachelor's degree in range management or range science. Summer jobs in range management or ranching can provide practical experience. Range managers may work for government agencies, mining companies, and large ranches.



Chemical laboratory technicians help in the installation and operation of laboratory equipment.

Chemical Laboratory Technician The chemical laboratory technician assists chemists and chemical engineers by conducting many of the practical experiments and tests performed in the laboratory.

In research and development, technicians observe various experiments and record all data. They help in the installation and operation of laboratory equipment. They may also be asked to collect and analyze samples.

A person seeking to become a chemical laboratory technician should take high school courses in biology, earth science, chemistry, and ecology. A mathematics course such as algebra should also be included.

Students thinking of this as a possible career should be interested in science projects and have a liking for finding the why and how of things. They should have the ability to do careful and precise work and to keep accurate records. Many employers would also expect additional technical or junior-college training. Some employers, however, will give on-the-job training for high school graduates.

Figure 12-11. Earth processes can continue uninterrupted on wetlands like this salt marsh in northwest Florida.

People have come to appreciate the value of wetlands as a preserve for many living species and for their value in fighting water pollution. On a much larger scale, people are coming to appreciate the role that the entire earth plays in providing a suitable environment for life. The depletion and pollution of earth materials and the interruption of earth processes affect all living organisms.

Check yourself

1. What effect did the oil crisis of the early 1970s have on people's attitudes toward the earth's natural resources?
2. How is government acquisition of wetlands important to the environment?

Activity Evaluating Alternative Energy Sources on Klar

Materials

data table on this page

Purpose

To select the best fuel for a new power plant on the imaginary planet Klar.

What to Do

1. Imagine that you are the regional utility manager on an imaginary planet called Klar. As a result of population growth, a new power plant must be built. You have four fuels to select from. They are listed on the data table.
2. On a separate piece of paper, calculate the annual costs for items A, B, and C. (For each, divide the total cost by the years of use.)
3. Also find the total annual cost (the sum of annual costs for items A through E) for each energy source.

Questions

1. For Fuel 1, what is the annual cost of items A, B, and C? For Fuel 2? Fuel 3? Fuel 4?
2. What is the total annual cost for Fuel 1? Fuel 2? Fuel 3? Fuel 4?

Conclusion

Using data and other considerations you feel important, recommend a fuel and give reasons for your choice.

Data Table for Evaluating Alternative Energy Sources

Energy Source		1 (a liquid that is burned)	2 (a solid that is burned)	3 (a radioactive fuel)	4 (solar energy)
A. Cost of Plant	total cost	3000	3000	4000	6000
	years of use	30	30	20	30
B. Special Equipment	total cost	500	500	400	2000
	years of use	20	20	20	20
C. Pollution-Control Equipment	total cost	100	200	50	0
	years of use	10	10	10	
D. Operating Expenses	annual cost	50	50	50	50
E. Fuel Costs	annual cost	100	50	30	0
F. Pollution Index Value		1.0	1.5	0.2	0

Chapter 12 Review

Check Your Vocabulary

incinerate	reforestation
landfill	strip mines
quarry	wetlands
recycled	

Match each term above with the numbered phrase that best describes it.

1. Replanting a forest with new seedlings as trees are removed
2. Huge open pits, near the earth's surface, from which minerals have been removed
3. Changed into a usable form and used again
4. To burn up completely
5. A large pit in the ground which is filled with layer upon layer of garbage
6. Coastal and freshwater swamps
7. A strip mine dug to obtain building stone

Check Your Knowledge

Multiple Choice: Choose the answer that best completes each of the following sentences.

1. The earth's natural landscapes are the result of _?_.
   a) farming
   b) suburban sprawl
   c) natural processes
   d) mining
2. Bingham Canyon, Utah, is the location of _?_.
   a) rich iron ores
   b) the world's largest strip mine
   c) a surface quarry
   d) a reforestation project
3. At the present time, recycling takes care of _?_ of the solid waste materials.
   a) most   c) none
   b) about half   d) a small amount
4. In a landfill area, the heat and pressure of _?_ cause the biodegradable materials to decompose.
   a) incinerators
   b) old automobiles
   c) overlying layers of solid waste
   d) fires
5. Disposing of _?_ is also a problem because they do not decompose.
   a) iron and tin cans
   b) plastic and rubber products
   c) paper goods and food scraps
   d) dead plant materials

Check Your Understanding

1. How has the change in population affected our attitude toward the land and its resources?
2. How has our present way of life increased the demands that are being placed on the earth as a source of needed materials?
3. Why is solid-waste disposal becoming an increasingly greater problem?
4. How can the recycling of waste materials affect the environment?
5. How can government acquisition of land benefit the environment?

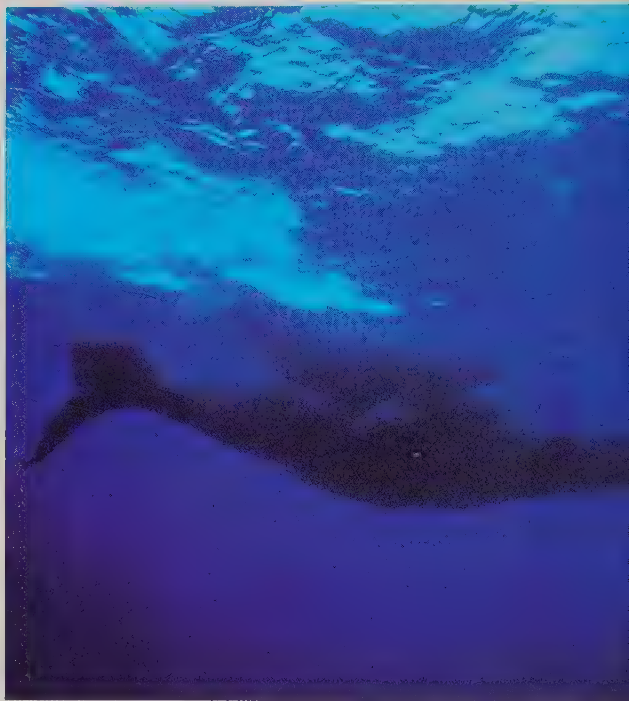
Science Issues of Today Extinction Patterns and Rates

The Geologic Time Scale is mostly based on divisions in earth history that are characterized by different life forms. Trilobites mark the beginning of the Paleozoic Era, and become extinct near the end of that time. But throughout the Paleozoic Era many different species of trilobites developed, thrived, and then became extinct. The Mesozoic Era was the age of the dinosaurs. Many of these magnificent reptilian species developed and became extinct, with the last species surviving until the end of the Mesozoic Era.

This pattern of life forms developing, living, and becoming extinct has been repeated tens of thousands of times with different types of organisms. This pattern is a part of the natural processes of life on earth.

What causes the extinctions? No single answer can be given to this question because many natural phenomena can cause extinctions. Large meteorites striking the earth can create dust clouds that block the sun and cause major weather changes. Disease can ravage populations. Periods of excessive volcanism can cause instant kills and longer-term weather changes. Variations in continental positions on the earth's surface due to plate tectonic movements can change environments and climate patterns. Genetic changes in response to solar radiation or chemicals entering the environment from the weathering of rocks and minerals also affect organisms. Glacial epochs are accompanied by a lowering of sea level and a change in temperature. The development of a predator or competitor in the environment can rapidly destroy a species. The number of possibilities goes on and on.

Rates of extinction for different species can be determined from an examination of the rock record. The extinction rate is highly variable depending upon the type of organism involved.



A humpback cow and her calf stay close together for at least a year.

Species of reptiles, for example, might have longer life spans than species of crabs. Most organisms are unaware of extinction patterns and rates.

People, however, are in the unique position of not only knowing about other organisms, past and present, but also of being able to drastically alter the environment and extinction rates. This gives us the responsibility to learn how we are affecting the environment and its life forms. One of our single greatest challenges is to understand our environment and protect it, so that we will beautify and enhance the earth and its living creatures.

Appendix

Relative Humidity Table: Celsius

Wet-Bulb Depression (°C) (Dry-bulb temperature minus wet-bulb temperature)

Dry-Bulb Temperature(°C)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
−10	67	35																		
−8	71	43	15																	
−6	74	49	25																	
−4	77	55	33	12																
−2	79	60	40	22																
0	81	64	46	29	13															
2	84	68	52	37	22	7														
4	85	71	57	43	29	16														
6	86	73	60	48	35	24	11													
8	87	75	63	51	40	29	19	8												
10	88	77	66	55	44	34	24	15	6											
12	89	78	68	58	48	39	29	21	12											
14	90	79	70	60	51	42	34	26	18	10										
16	90	81	71	63	54	46	38	30	23	15	8									
18	91	82	73	65	57	49	41	34	27	20	14	7								
20	91	83	74	66	59	51	44	37	31	24	18	12	6							
22	92	83	76	68	61	54	47	40	34	28	22	17	11	6						
24	92	84	77	69	62	56	49	43	37	31	26	20	15	10	5					
26	92	85	78	71	64	58	51	46	40	34	29	24	19	14	10	5				
28	93	85	78	72	65	59	53	48	42	37	32	27	22	18	13	9	5			
30	93	86	79	73	67	61	55	50	44	39	35	30	25	21	17	13	9	5		
32	93	86	80	74	68	62	57	51	46	41	37	32	28	24	20	16	12	9	5	
34	93	87	81	75	69	63	58	53	48	43	39	35	30	26	23	19	15	12	8	5
36	94	87	81	75	70	64	59	54	50	45	41	37	33	29	25	21	18	15	11	8
38	94	88	82	76	71	66	61	56	51	47	43	39	35	31	27	24	20	17	14	11
40	94	88	82	77	72	67	62	57	53	48	44	40	36	33	29	26	23	20	16	14

Relative Humidity Table: Fahrenheit

Weather Bureau Bulletin 235, 1941

Wet-Bulb Depression (°F) (Dry-bulb temperature minus wet-bulb temperature)

Dry-Bulb Temperature (°F)	1	2	3	4	5	6	7	8	9	10	15	20	25	30	35	40	45
10	78	60	34	13													
15	82	67	46	29	11												
20	85	70	55	40	26	12											
25	87	74	62	49	37	25	13										
30	89	78	67	56	46	36	26	16	6								
35	91	81	72	63	54	45	36	27	19	10							
40	92	83	75	68	60	52	45	37	29	22							
45	93	86	78	71	64	57	51	44	38	31							
50	93	87	80	74	67	61	55	49	43	38	10						
55	94	88	82	76	70	65	59	54	49	43	19						
60	94	89	83	78	73	68	63	58	53	48	26	5					
65	95	90	85	80	75	70	66	61	56	52	31	12					
70	95	90	86	81	77	72	68	64	59	55	36	19	3				
75	96	91	86	82	78	74	70	66	62	58	40	24	9				
80	96	91	87	83	79	75	72	68	64	61	44	29	15	3			
85	96	92	88	84	80	76	73	70	66	62	46	32	20	8			
90	96	92	89	85	81	78	74	71	68	65	49	36	24	13	3		
95	96	93	89	86	82	79	76	72	69	66	52	38	28	18	8		
100	96	93	89	86	83	80	77	73	70	68	54	41	30	21	12	4	
105	97	93	90	87	84	80	78	74	72	69	56	44	34	24	15	8	1

Dew-Point Temperature Table: Celsius

Wet-Bulb Depression (°C) (Dry-bulb temperature minus wet-bulb temperature)

Dry-Bulb Temperature (°C)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
-10	-15	-22																		
-8	-12	-18	-30																	
-6	-9	-14	-23																	
-4	-7	-11	-17	-30																
-2	-5	-8	-13	-20																
0	-2.5	-6	-10	-15	-25															
2	-0.5	-3	-7	-11	-18	-30														
4	2	-1	-4	-7.5	-12	-17														
6	4	1.5	-1	-4	-8	-14	-22													
8	6	4	1	-1.7	-4.5	-9	-15	-20												
10	8	6	4	1	-1.5	-5	-9.5	-15	-28											
12	10	9	6	4	1	-2	-5.5	-10	-16	-30										
14	12	11	8	6	4	1	-2	-6	-10	-17.5										
16	14	12.5	10.7	8.5	6	4	1	-2	-6	-10	-18									
18	16	14.5	13	11	9	6.5	4	1	-2	-4.5	-10	-18								
20	18	16.7	15	13	10.5	9.5	7	4.5	2	-1	-5	-10	-18							
22	20	18.7	17	16	13.5	11.5	10	7.5	5	2	-1.5	-5	-10	-18						
24	22	20.7	19	17.5	16	14	12	10	8	5	2.5	-1	-5	-10	-18					
26	24	22.7	21	19.5	18	16.5	15	13	10.5	8	6	3	-1	-5	-10	-18				
28	26	24.7	23	22	20	19	17	15	13	11	9	6	3	-1	-5	-10	-18			
30	28	26.7	25	24	22	21.5	20	18	16	14	12	10	6	3	-1	-5	-10	-18		
32	30	28.7	27	26	24	23	22	20	18	17	15	13	10	6	3	-1	-5	-10	-18	
34	32	30.7	29	28	26	25	24	22	20	19	17	15	13	10	6	3	-1	-5	-10	-18
36	34	32.7	31	30	28	27	26	24	22	21	19	17	15	13	10	6	3	-1	-5	-10
38	36	34.7	33	32.5	30	29	28	26	24	23	21	19	17	15	13	10	6	3	-1	-5
40	38	36.9	35	34	32	31	30	28	26	25	23	21	19	17	15	13	10	6	3	-1

Dew-Point Temperature Table: Fahrenheit

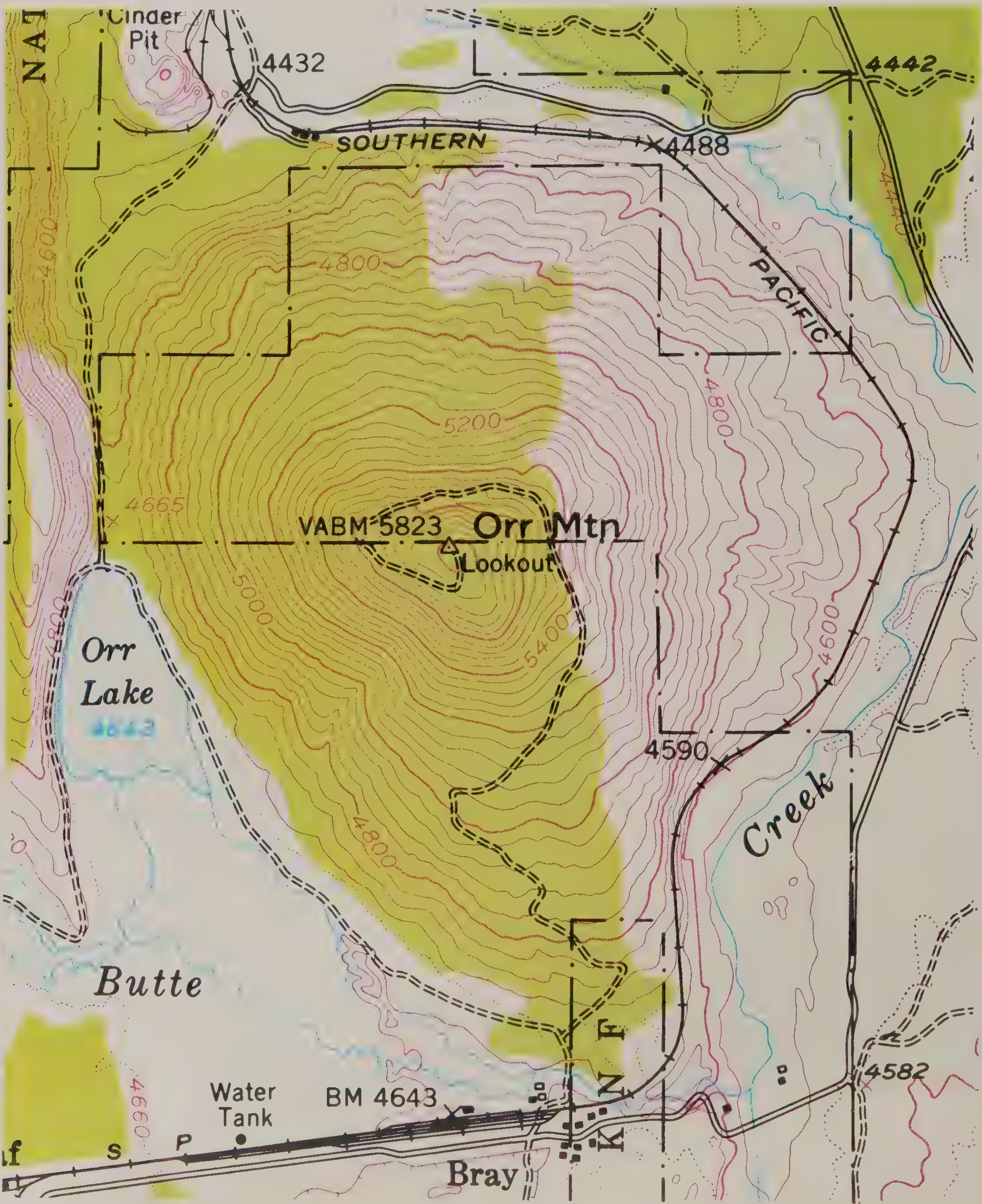
Weather Bureau Bulletin 235, 1941

Wet-Bulb Depression (°F) (Dry-bulb temperature minus wet-bulb temperature)

Dry-Bulb Temperature (°F)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
10	5	−2	−10	−27												
15	11	6	0	−9	−26											
20	16	12	8	2	−7	−21										
25	22	19	15	10	5	−3	−15	−51								
30	27	25	21	18	14	8	2	−7	−25							
35	33	30	28	25	21	17	13	7	0	−11						
40	38	35	33	30	28	25	21	18	13	7						
45	43	41	38	36	34	31	28	25	22	18						
50	48	46	44	42	40	37	34	32	29	26	0					
55	53	51	50	48	45	43	41	38	36	33	15					
60	58	57	55	53	51	49	47	45	43	40	25	−8				
65	63	62	60	59	57	55	53	51	49	47	34	14				
70	69	67	65	64	62	61	59	57	55	53	42	26	−11			
75	74	72	71	69	68	66	64	63	61	59	49	36	15			
80	79	77	76	74	73	72	70	68	67	65	56	44	28	−7		
85	84	82	81	80	78	77	75	74	72	71	62	52	39	19		
90	89	87	86	85	83	82	81	79	78	76	69	59	48	32	1	
95	93	93	91	90	89	87	86	85	83	82	74	66	56	43	24	
100	99	98	96	95	94	93	91	90	89	87	86	72	63	52	37	12

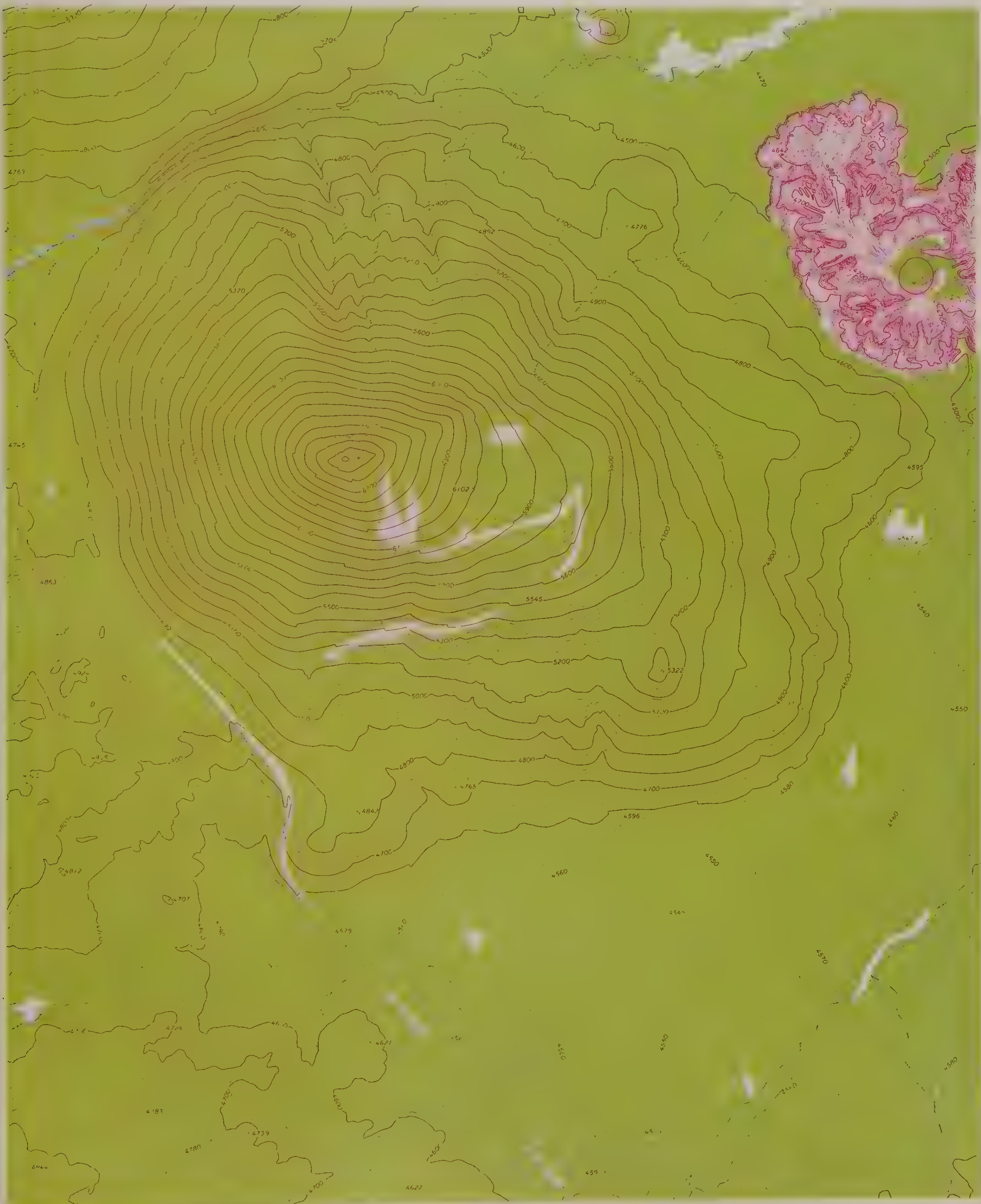
Topographic Map of Orr Mountain

(adapted from a USGS map for Bray, California)



Topographic Map of Odell Butte

(adapted from USGS maps for Crescent Lake, Oregon, and Odell Butte, Oregon)

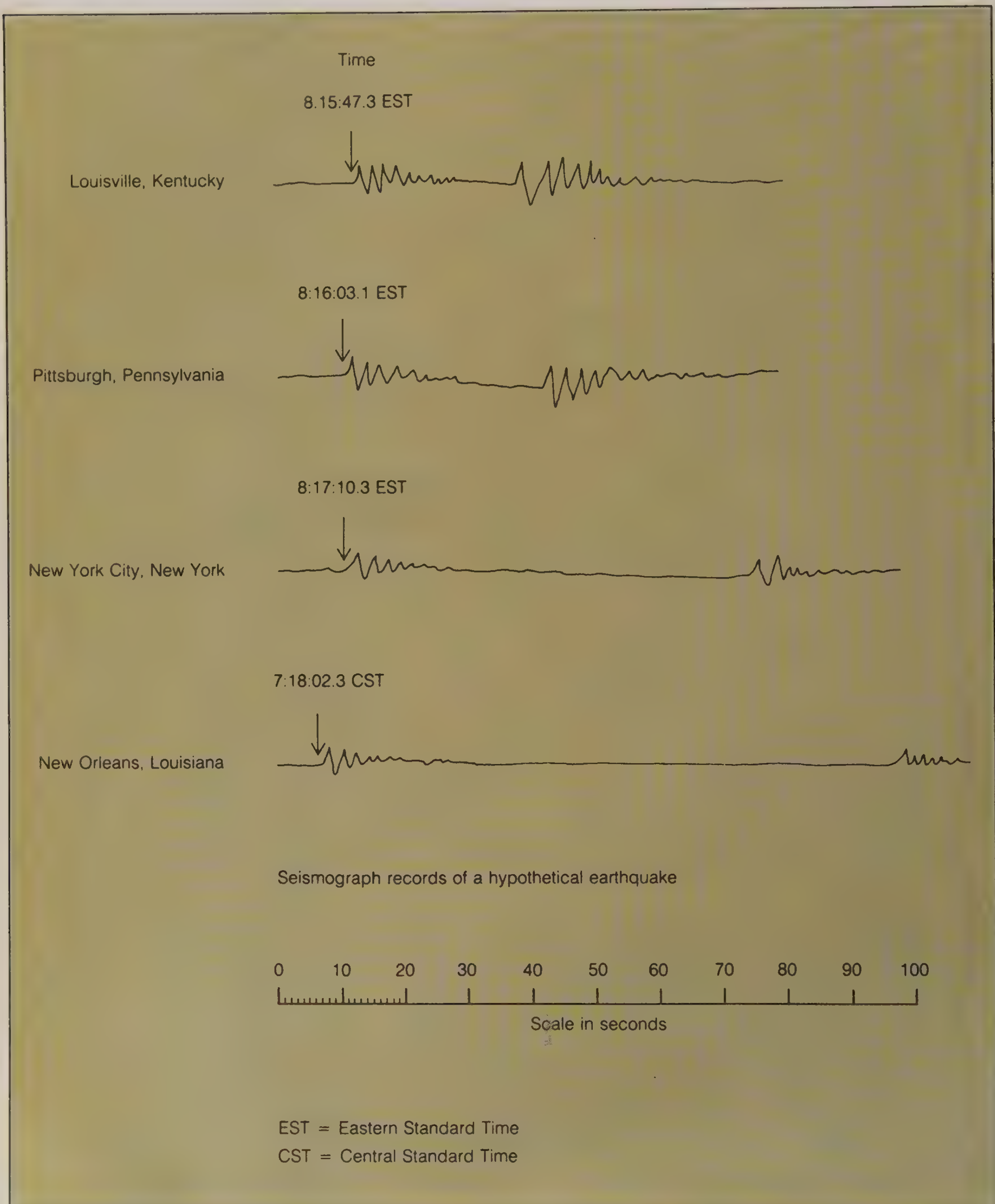


Topographic Map of Crater Lake

(adapted from a USGS map for Crater Lake National Park and Vicinity, Oregon)


Grouse Hill
Sharp Pk
Mazama Rock
DRIVE
Steel Bay
Cleetwood Cove
Pumice Pt
Palisade Pt
Roundtop
Palisades
Wineglass
Grotto Cove
Bear Butte
Bear
Creek
Scout Hill
BM 6432
Cascade Spr
Skell Head
TER LAKE
ELEVATION 6176 FEET
DEPTH ABOUT 2000 FEET
Scott Bluffs
Pothole
Pothole Spr
Creek
Cloudcap Bay
Redcloud Cliff
Cloudcap
Sentinel Rock
Castle Rock
Victor View
Lookout
Mt Scott
VABM 8926
Danger Bay
Eagle Pt
Phantom Ship
Chaski Bay
Kerr Notch
Anderson Spr
BM 7088
ANDERSON BLUFFS
Dutton Cliff
Sun Notch
Crags
Applegate Pk
Kerr Valley
Dutton Ridge
Spring
Scott
Sand
Vidae
Vidae Cliff
Meadow
Lost Creek Campground
BM 5972
Lost Cr
Creek
Wheeler
Cavern
Tututni Pass
Ridge
Valley
BM 5664

Seismographic Records of a Hypothetical Earthquake



Map of the Eastern United States

Periodic Table of the Elements

Key	
11	Atomic number
Ⓢ	State
Na	Element symbol
Sodium 22.990	Average atomic mass

State:
Ⓢ Solid
Ⓛ Liquid
Ⓖ Gas
Ⓝ Not found in nature

Metals | Nonmetals

1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	0
1 Ⓖ **H** Hydrogen 1.0079																	2 Ⓖ **He** Helium 4.0026
3 Ⓢ **Li** Lithium 6.941	4 Ⓢ **Be** Beryllium 9.0122											5 Ⓢ **B** Boron 10.81	6 Ⓢ **C** Carbon 12.011	7 Ⓖ **N** Nitrogen 14.007	8 Ⓖ **O** Oxygen 15.999	9 Ⓖ **F** Fluorine 18.998	10 Ⓖ **Ne** Neon 20.179
11 Ⓢ **Na** Sodium 22.990	12 Ⓢ **Mg** Magnesium 24.305											13 Ⓢ **Al** Aluminum 26.982	14 Ⓢ **Si** Silicon 28.086	15 Ⓢ **P** Phosphorus 30.974	16 Ⓢ **S** Sulfur 32.06	17 Ⓖ **Cl** Chlorine 35.453	18 Ⓖ **Ar** Argon 39.948
19 Ⓢ **K** Potassium 39.098	20 Ⓢ **Ca** Calcium 40.08	21 Ⓢ **Sc** Scandium 44.956	22 Ⓢ **Ti** Titanium 47.90	23 Ⓢ **V** Vanadium 50.941	24 Ⓢ **Cr** Chromium 51.996	25 Ⓢ **Mn** Manganese 54.938	26 Ⓢ **Fe** Iron 55.847	27 Ⓢ **Co** Cobalt 58.933	28 Ⓢ **Ni** Nickel 58.71	29 Ⓢ **Cu** Copper 63.546	30 Ⓢ **Zn** Zinc 65.38	31 Ⓢ **Ga** Gallium 69.72	32 Ⓢ **Ge** Germanium 72.59	33 Ⓢ **As** Arsenic 74.922	34 Ⓢ **Se** Selenium 78.96	35 Ⓛ **Br** Bromine 79.904	36 Ⓖ **Kr** Krypton 83.80
37 Ⓢ **Rb** Rubidium 85.468	38 Ⓢ **Sr** Strontium 87.62	39 Ⓢ **Y** Yttrium 88.906	40 Ⓢ **Zr** Zirconium 91.22	41 Ⓢ **Nb** Niobium 92.906	42 Ⓢ **Mo** Molybdenum 95.94	43 Ⓝ **Tc** Technetium (97)	44 Ⓢ **Ru** Ruthenium 101.07	45 Ⓢ **Rh** Rhodium 102.91	46 Ⓢ **Pd** Palladium 106.4	47 Ⓢ **Ag** Silver 107.87	48 Ⓢ **Cd** Cadmium 112.41	49 Ⓢ **In** Indium 114.82	50 Ⓢ **Sn** Tin 118.69	51 Ⓢ **Sb** Antimony 121.75	52 Ⓢ **Te** Tellurium 127.60	53 Ⓢ **I** Iodine 126.90	54 Ⓖ **Xe** Xenon 131.30
55 Ⓢ **Cs** Cesium 132.91	56 Ⓢ **Ba** Barium 137.33	71 Ⓢ **Lu** Lutetium 174.97	72 Ⓢ **Hf** Hafnium 178.49	73 Ⓢ **Ta** Tantalum 180.95	74 Ⓢ **W** Tungsten 183.85	75 Ⓢ **Re** Rhenium 186.21	76 Ⓢ **Os** Osmium 190.2	77 Ⓢ **Ir** Iridium 192.22	78 Ⓢ **Pt** Platinum 195.09	79 Ⓢ **Au** Gold 196.97	80 Ⓛ **Hg** Mercury 200.59	81 Ⓢ **Tl** Thallium 204.37	82 Ⓢ **Pb** Lead 207.2	83 Ⓢ **Bi** Bismuth 208.98	84 Ⓢ **Po** Polonium (209)	85 Ⓢ **At** Astatine (210)	86 Ⓖ **Rn** Radon (222)
87 Ⓢ **Fr** Francium (223)	88 Ⓢ **Ra** Radium 226.03	103 Ⓢ **Lr** Lawrencium (260)	104* Ⓝ (261)	105* Ⓝ (262)	106* Ⓝ (263)	107* Ⓝ (264)		109* Ⓝ (266)									

*Name not officially assigned

Lanthanide Series													
57 Ⓢ **La** Lanthanum 138.91	58 Ⓢ **Ce** Cerium 140.12	59 Ⓢ **Pr** Praseodymium 140.91	60 Ⓢ **Nd** Neodymium 144.24	61 Ⓝ **Pm** Promethium (145)	62 Ⓢ **Sm** Samarium 150.4	63 Ⓢ **Eu** Europium 151.96	64 Ⓢ **Gd** Gadolinium 157.25	65 Ⓢ **Tb** Terbium 158.93	66 Ⓢ **Dy** Dysprosium 162.50	67 Ⓢ **Ho** Holmium 164.93	68 Ⓢ **Er** Erbium 167.26	69 Ⓢ **Tm** Thulium 168.93	70 Ⓢ **Yb** Ytterbium 173.04

Actinide Series													
89 Ⓢ **Ac** Actinium (227)	90 Ⓢ **Th** Thorium 232.04	91 Ⓢ **Pa** Protactinium 231.04	92 Ⓢ **U** Uranium 238.03	93 Ⓝ **Np** Neptunium 237.05	94 Ⓝ **Pu** Plutonium (244)	95 Ⓝ **Am** Americium (243)	96 Ⓝ **Cm** Curium (247)	97 Ⓝ **Bk** Berkelium (247)	98 Ⓝ **Cf** Californium (251)	99 Ⓝ **Es** Einsteinium (254)	100 Ⓝ **Fm** Fermium (257)	101 Ⓝ **Md** Mendelevium (258)	102 Ⓝ **No** Nobelium (259)

Glossary

Pronunciation Key

A simple, phonetic pronunciation is given for words that may be unfamiliar or hard to pronounce. (ad′-ee-uh-BAT′-ik), for example, indicates how to say the word *adiabatic*.

Capital letters followed by an accent mark indicate the syllable that receives the heaviest stress (*bat* in the word *adiabatic*). An accent mark following a lowercase syllable (the first syllable in the representation for *adiabatic*) indicates a syllable that receives a secondary stress.

Most of the time, the phonetic pronunciations can be interpreted without referring to the following key, which gives the sound of letters that are commonly used for more than one sound.

Pronunciation Key

a	c**a**t	g	**g**rass	ow	n**ow**
ah	f**a**ther	i	h**i**m	oy	b**oy**
ar	c**ar**	ī	k**ī**te	s	**s**o
ay	s**ay**	j	**j**am	sh	**sh**ine
ayr	**air**	ng	si**ng**	th	**th**ick
e, eh	h**e**n	o	fr**o**g	TH	**th**en
ee	m**ee**t	ō	h**o**le	u, uh	s**u**n
eer	d**eer**	oo	m**oo**n	z	**z**ebra
ew	n**ew**	or	f**or**	zh	plea**s**ure

Glossary

abrasion (uh-BRAY′-zhin) The physical weathering process in which particles rub and scrape and hit against each other. (p. 446)

absolute age Age expressed in years. (p. 542)

absolute magnitude The apparent brightness that a star would have if it were 32.6 light years from the earth. (p. 211)

abyssal plain (uh-BUS′-ul) Large flat area of the deep sea floor; formed by sediment flows that spill off the continental margins. (p. 379)

adhesion (ad-HEE′-zhin) The attraction of water molecules to other kinds of molecules. (p. 354)

adiabatic change (ad′-ee-uh-BAT′-ik) A change in temperature that occurs solely because of the expansion or compression of a material and not because of any heat exchange between different materials. (p. 320)

air mass A large body of air that has about the same amount of moisture and about the same temperature throughout. (p. 287)

altitude (AL′-tuh-tood′) The distance in degrees of a star above the horizon. (p. 121)

amino acids (uh-MEE′-nō AS′-idz) Compounds that form within living organisms and that can be used for age determination of certain earth materials. (p. 550)

anticline (AN′-ti-klīn′) An upward-arching fold in rocks. (p. 486)

aphotic zone (a′-FŌT′-ik ZŌN) The part of the ocean that is in total darkness. (p. 397)

apogee (AP′-uh-jee′) The point of the moon's elliptical orbit farthest from the earth. (p. 175)

apparent brightness The brightness of a star as observed from the earth. (p. 211)

apparent solar time (uh-PAR′-int) Time as determined by using the actual position of the sun. (p. 140)

aquifer (A′-kwuh-fer) A layer of permeable rock through which water travels. (p. 359)

artesian spring (ar-TEE′-zhin) A natural flow of water from an artesian formation. (p. 360)

artesian system (ar-TEE′-zhin) A combination of rock layers in which water passes downward through a permeable rock layer that is between two layers of impermeable rock. (p. 359)

assumption (uh-SUM′-shin) The taking for granted that certain processes and scientific laws are constant through time and place; for example, the laws of chemistry and physics. (p. 526)

asteroids (AS′-ter-oidz′) Fragments of rocky objects that revolve around the sun and that are smaller than planets. (p. 199)

asthenosphere (as-THEN′-uh-sfir) The layer of the earth immediately below the lithosphere; includes the low-velocity zone. (p. 504)

astronomical unit (as′-truh-NOM′-i-k′l) The distance between the earth and the sun (93 million mi; 149.67 million km), often used as a standard of comparison for measuring distances within the solar system. (p. 200)

astronomy (uh-STRON′-uh-mee) The science that is concerned with the size, composition, structure, and movement of all objects in space. (p. 18)

atmosphere (AT′-muh-sfir′) The blanket of air and other materials that completely covers the earth's lithosphere and hydrosphere; mainly nitrogen (4/5) and oxygen (1/5). (p. 17, 233)

atmospheric pressure (at′-mus-FER′-ik PRESH′-er) The pressure that the atmosphere, which has mass, exerts against the surface of the earth; also called barometric pressure. (p. 255)

atom (AT′-um) The smallest complete part of an element which contains all the properties of that element. (p. 60)

atomic energy (uh-TOM′-ik) Energy that is derived from the atoms of certain earth materials; also called nuclear energy. (p. 103)

aurora (uh-ROR′-uh) A natural light show that is caused by the effects of solar wind in the earth's upper atmosphere. (p. 189)

axis (AK′-sis) An imaginary line around which the earth appears to be turning. (p. 132)

azimuth (AZ′-uh-muth) The distance of a star in degrees on the horizon as measured in a clockwise direction from true north. (p. 125)

barometer (buh-ROM′-uh-ter) The basic instrument for measuring atmospheric pressure. (p. 256)

base level The limit to the downward erosion of a river; established by the level of the body of water into which the river flows. (p. 442)

bedrock A layer of solid rock that is under every soil. (p. 431)

binary stars (BĪ′-ner-ee) Two stars that revolve around each other. (p. 215)

biosphere (BĪ′-uh-sfir) The region near the earth's surface where all life is found. (p. 17)

black hole A very dense object with such strong gravitational force that not even light can escape from it. (p. 222)

blizzard A storm produced when thunderstorm conditions occur at below freezing temperatures; characterized by heavy snow and strong winds. (p. 311)

caldera (kal-DIR′-uh) A large circular depression that forms when a volcanic mountaintop collapses into the magma chamber beneath the mountain. (p. 472)

capillary action (KAP′-uh-ler′-ee) The upward movement of water in soil due to adhesion and cohesion. (p. 355)

capillary fringe (KAP′-uh-ler′ee) An area just above the water table that receives its moisture from the zone of saturation by capillary action. (p. 355)

celestial sphere (suh-LES′-chul SFIR) The imaginary sphere on which all objects in the sky seem to be located. (p. 117)

Cepheid variable (SEF′-ee-id) or (SEE′-fee-id) A star that gets brighter and dimmer at regular intervals. (p. 215)

chemical property (KEM′-uh-kul PROP′-er-tee) A feature of the way one substance reacts with another substance. The fact that silver tarnishes is a chemical property of silver. Compare *physical property*. (p. 9)

chemical weathering (KEM′-uh-kul) A kind of weathering in which different substances are formed. (p. 426)

chromosphere (KRŌ′-muh-sfir′) A thin layer that marks the change between the photosphere and the corona. (p. 187)

cinder cone A small volcanic mountain with steep sides. (p. 477)

circumference (ser-KUM′-fer-ins) The distance around a circular object. (p. 33)

Circum-Pacific Ring of Fire (SER′-kum) The entire group of volcanoes located around the Pacific Ocean. (p. 480)

circumpolar stars (ser′-kum-PŌ′-ler) Stars always found near the North Pole or South Pole. (p. 150)

cirrus clouds (SIR′-us) Wispy, feathery-looking clouds that are so thin that sunlight can pass through them. (p. 278)

classifying The grouping of similar events or objects, based upon observed properties or characteristics. (p. 7)

cleavage (KLEE′-vij) The ability of a mineral to break into smooth, parallel surfaces. (p. 68)

climate (KLĪ′-mit) The weather patterns that occur in one place over a period of a year or longer; determined primarily by average amounts of precipitation and average temperatures. (p. 316)

climate graph A graph that indicates average monthly temperature and precipitation conditions for twelve months at a particular location. (p. 325)

clouds Droplets of water that condense on tiny particles of dust and other solid matter in the sky above the earth's surface when the air is cooled below its dew point. (p. 277)

coal A solid fossil fuel. (p. 97)

cohesion (kō-HEE′-zhin) The attraction of one molecule to another molecule of the same kind. (p. 355)

cold front A weather front that forms when a cold air mass pushes a warm air mass ahead of it. (p. 290)

comet (KOM′-it) An object with a very oblong orbit that forms a long glowing tail as it approaches the sun. (p. 205)

compass (KUM′-pis) An instrument with a needle that points to the North Magnetic Pole. (p. 49)

composite cone (kum-POZ′-it) A volcanic mountain built of alternate layers of lava flows and volcanic cinders and ashes. (p. 479)

compound A substance that is made up of two or more elements that are joined together in fixed proportions. (p. 60)

compressional stress A form of stress in which matter is pushed together. (p. 487)

condensation (kon-den-SAY′-shin) The changing of a vapor into a liquid. (p. 264)

condense (kun-DENS′) To change from a gas to a liquid. (p. 337)

conduction (kun-DUK′-shin) The movement of energy through a material without the material itself moving. (p. 235)

constellation (kon′-stuh-LAY′-shin) A group of stars in which some people have imagined the outline of a person or animal. (p. 119)

continental air mass An air mass that forms over dry land. (p. 287)

continental climate A climate influenced mainly by continental air masses; characterized by dry air. (p. 318)

continental crust Crustal rock that is granitic and that is between 20 and 60 km thick. (p. 503)

continental drift See *theory of continental drift.*

continental glacier An ice sheet that flows outward from its thick center over wide regions of a landscape. (p. 444)

continental margin The region of the ocean bottom near the land areas; contains most of the sediment eroded from the land; separates a continent from the deep sea floor. (p. 374)

contour interval (KON′-toor IN′-ter-vul) The difference in elevation between any two contour lines on a topographic map. (p. 46)

contour line (KON′-toor LĪN) A line that connects places that have the same elevation, indicating at the same time the shapes of land features at various elevations. (p. 45)

convection (kun-VEK′-shin) The movement of energy through a material because of some movement within the material. (p. 235)

convection current The movement of a fluid caused by unequal densities of portions of the fluid that have been heated unequally. (p. 239)

Coriolis effect (kor′-ee-Ō′-lis) The apparent deflection of an object that is traveling above the earth's surface; caused by differences in rotational speeds on the earth's surface. (p. 139)

corona (kuh-RŌ′-nuh) The outermost part of the sun's atmosphere. (p. 187)

crest The highest point of a wave. (p. 403)

crystal The solid shape produced when mineral grains have complete freedom to form in any direction. (p. 64)

crystalline solid (KRIS′-tuh-lin) A solid substance whose atoms are locked together into fixed patterns that repeat in three dimensions—height, width, and depth or thickness. All minerals are crystalline solids. (p. 63)

cumulonimbus cloud (kyoom′-yuh-lō-NIM′-bus) A massive vertical cloud containing huge amounts of moisture; associated with thunderstorms. (p. 309)

cumulus clouds (kyoom′-yuh-lis) Puffy clouds that look like large cotton balls. (p. 277)

data (DĀT′-uh) or (DAT′-uh) A collection of observations. (p. 7)

daylight-saving time An adjusted time during which clocks are one hour ahead of standard time to provide an hour more of daylight at the end of a working day. (p. 144)

deflected (di-FLEK′-tid) Forced from a straight line of travel. (p. 137)

deformation See *plastic deformation.*

density The mass of 1 cm^3 of a material. (p. 31)

deposition (dep′-uh-ZISH′-un) or (dee′-puh-ZISH′-un) The process whereby particles and fragments of earth materials are deposited, or are laid down, by an agent of erosion. (p. 454)

derived unit A unit of measure that is derived from two or more base units. (p. 28)

desert Any area where the total amount of precipitation is less than 10 in. (254 mm) per year; can even be an area on the surface of the ocean. (p. 322)

dew Droplets of water that condense on objects on the earth's surface when night air is cooled below its dew-point temperature. (p. 274)

dew-point temperature The temperature to which air must be cooled to reach its saturation point; same as saturation temperature. (p. 273)

dike A layer of igneous rock that is younger than and at an angle to the other rock layers in a formation. (p. 539)

direct observation Information that is received by means of one or more of the five senses. (p. 5)

discontinuity (dis′-kan-tuh-NOO′-uh-tee) A boundary between two divisions of the earth's interior; indicated by sharp changes in earthquake wave velocity. (p. 503)

disphotic zone (dis′-FŌT′-ik ZŌN) A zone of reduced light in the ocean; between 200 m and 1000 m below the surface. (p. 397)

divide The highest land that separates the direction in which water will run off the earth's surface. (p. 343)

Doppler effect (DOP′-ler) Changes in sound waves or light waves as one object moves toward or away from another object. (p. 151, 214)

drumlin A smoothly rounded teardrop-shaped hill of glacial till. (p. 463)

earthquake A motion, trembling, or vibration of the earth; caused by the release of stress that has been slowly building up in the earth's crust. (p. 494)

echo sounding A method of using noise (pings) to measure the depth of the ocean. (p. 373)

electromagnetic spectrum (i-lek′-trō-mag-NET′-ik SPEK′-trum) The energy waves of all the different wavelengths of energy from the sun. (p. 234)

electromagnetic waves (i-lek′-tro-mag-NET′-ik) Energy waves similar to the waves produced by an electromagnet; how the sun's energy travels. (p. 233)

element (EL′-uh-mint) A substance that contains only one kind of atom. (p. 60)

elevation (el′-uh-VAY′-shun) Height above sea level. (p. 45)

ellipse (i-LIPS′) A smooth, closed curve that is not a perfect circle. (p. 175)

end moraine (muh-RAYN′) A deposit formed at the foot of a glacier. (p. 461)

epicenter (EP′-uh-sen′-ter) The point on the earth's surface directly above the focus. (p. 495)

equator (i-KWAYT′-er) An imaginery line that circles the earth halfway between the North and South Poles, at 0° latitude. (p. 37)

equinox (EE′-kwuh-noks′) The time of the year when the sun crosses the equator on its way to the Tropic of Cancer or the Tropic of Capricorn. (p. 159)

era (IR′-uh) One of the four large units of geologic time. (p. 554)

erosion (i-RŌ′-zhin) The transporting of the products of weathering. (p. 438)

erratics (i-RAT′-iks) Large water-worn boulders that have been deposited by a glacier. (p. 444)

evaporate (i-VAP′-uh-rayt′) To change from a liquid to a gas. (p. 337)

evaporation (i-vap-er-AY′-shin) The changing of a substance from a liquid into a vapor. (p. 264)

evolve (i-VOLV′) To undergo changes over a period of time. (p. 535)

extinct (ik-STINGKT′) Died out without leaving any descendants. (p. 570)

fault A break or fracture in rocks along which the rocks move. (p. 491)

faunal succession See *principle of faunal succession.*

fission (FISH′-in) Atomic energy that is produced when certain large, unstable atoms are made to split apart to form atoms of a different element. (p. 103)

fissure (FISH′-er) A long crack in the ground from which lava flows. (p. 479)

flood plain The level area between the banks of a river and the foot of the mountains. (p. 441)

fluid (FLOO′-id) Any material that can move and change shape without separation. (p. 238)

focus (FŌ′-kis) The point of origin of an earthquake. (p. 494)

fog Droplets of water that condense on tiny particles of dust and other solid matter near the earth's surface when the air is cooled below its dew point. (p. 275)

folded rock Rock that has been bent by high confining pressure. (p. 486)

footwall The mass of rock that is below a fault. (p. 491)

formation A unit of rocks grouped together because of common properties that are widespread enough to be easily recognized and mapped. (p. 538)

fossil The skeletal remains or impressions of previously living life forms in rock that formed before written history. (p. 532)

fossil fuels Fuels formed from the remains of plants and animals that died long ago; they include oil, coal, and natural gas. (p. 96)

fossil record The record of former life forms as preserved in the earth's rocks. (p. 559)

fracture (FRAK′-cher) A crack that develops when rocks are folded. (p. 487)

freeze To change from a liquid to a solid. (p. 337)

freezing point The temperature at which a liquid freezes. (p. 391)

front The boundary between two air masses. (p. 290)

frost Ice crystals that form on objects on the earth's surface when the dew-point temperature of the air is below 0°C and the air is cooled below its dew point. (p. 274)

fumarole (FYOO′-muh-rōl′) A volcanic vent or opening that gases and smoke come out of. (p. 476)

fusion (FYOO′-zhin) Atomic energy that is produced when atoms of an element are fused together to form atoms of a different element. (p. 104)

galaxy (GAL′-ik-see) A large system of stars that is held together by gravitational attraction. (p. 219)

geologic time (jee′-uh-LOJ′-ik) The age of the earth as revealed in its rocks; expressed in eras and periods of time rather than in years. (p. 552)

geology (jee-OL′-uh-jee) The science that is concerned with the structure of the earth's lithosphere, its composition, and what causes it to change. (p. 18)

geothermal energy (jee′-ō-THER′-mul) Energy powered by heat from deep within the earth's crust. (p. 102)

geyser (GĪ′-zer) or (GĪ′-ser) The eruption from the ground of water and steam that have been heated by hot magma or hot igneous rocks in the earth's crust. (p. 360)

glacial lobe (GLAY′-shul) A tongue-like mass of ice that sticks out from the main mass of a glacier. (p. 461)

glacier (GLAY′-sher) A moving mass of ice and snow. (p. 340)

globe A ball-shaped physical model of the earth. (p. 36)

graphic scale of distance A line, divided into units of distance, that shows how a distance on a map compares to the actual distance on the earth's surface. (p. 45)

gravitation See *laws of gravitation.*

greenhouse effect The warming of the atmosphere that takes place because gases like carbon dioxide in the atmosphere are able to absorb energy in the wavelengths in which it is radiated from the earth. (p. 240)

Greenwich mean time (GREN′-ich) The mean solar time on the prime meridian. (p. 142)

ground water Water that has infiltrated the earth's surface. (p. 354)

gyre (JĪR) A closed system of rotating ocean currents. (p. 412)

hachures (huh-SHOORZ′) or (HASH′-oorz) Short lines drawn from a contour line to indicate direction of slope. (p. 46)

hail Layered formations of ice that build up as they are tossed through different layers of air within tall clouds; can become larger than golf balls before they finally fall to the earth's surface. (p. 280)

half-life The time it takes for one half of a radioactive material to decay. (p. 547)

hanging wall The mass of rock that is above a fault. (p. 491)

heat of fusion (FYOO′-zhin) The amount of heat needed for 1 g of a solid substance to melt and become a liquid. (p. 265)

heat of vaporization (vay′-per-uh-ZAY′-shin) The amount of heat needed for 1 g of a substance to become a vapor. (p. 264)

heft A rough-estimate weight test that compares the weight of a mineral sample to an equal-size sample of quartz. (p. 71)

high-pressure center The center of an area of high atmospheric pressure; indicated by the letter H or the word High on a pressure map. (p. 261)

high tide When the waterline of a body of water reaches its highest point. (p. 409)

horizon (huh-RĪ′-zun) The point where, to an observer, the earth and sky appear to meet. (p. 117)

humidity (hyoo-MID′-uh-tee) The amount of moisture that is in the air. (p. 266)

humus (HYOO′-mis) An organic substance rich in materials that plants need for growth. (p. 431)

hurricane (her′-uh-KAYN′) A very large circular storm with wind speeds of at least 64 knots; accom-

panied by dense clouds and heavy rain. (p. 312)

hydroelectric energy (hī′-drō-uh-LEK′-trik) Electricity produced by generators powered by moving water. (p. 100)

hydrology (hī-DROL′-uh-jee) The science that is concerned with the earth's entire hydrosphere, including the water below the earth's surface and the water in the earth's atmosphere. (p. 18)

hydrosphere (HĪ′-druh-sfir) All the water found on the earth, including the water that is below the ground and the water that is found in the atmosphere. (p. 17)

hypothesis (hī-POTH′-uh-sis) A possible answer to a question or a possible solution to a problem, based on observations. The plural form of *hypothesis* is *hypotheses*. (p. 11)

icebergs Floating masses of ice that broke off freshwater glaciers. (p. 394)

igneous rock (IG′-nee-is) Rock that is formed from hot melted materials. (p. 76)

impermeable (im-PER′-mee-uh-bul) Allowing no water to pass through. (p. 354)

impurities (im-PYOOR′-uh-teez) Atoms of elements other than the key elements of a mineral. (p. 66)

incinerate (in-SIN′-uh-rayt′) To burn up completely. (p. 589)

inclination (in′-kluh-NAY′-shin) The tilt of the earth's axis. (p. 154)

index fossil A guide fossil that geologists can use to determine the age of rock layers relative to other rock layers. (p. 532)

indirect observation An observation that requires the use of an instrument. (p. 6)

inertia See *law of inertia.*

inference (IN′-fer-ins) An interpretation of observations. (p. 9)

infiltration (in′-fil-TRAY′-shin) The process by which water sinks into porous earth materials like soil or porous rock. (p. 351)

inorganic (in-or-GAN′-ik) Not organic; formed, for the most part, without the help of plants and animals. (p. 65)

instrument A scientific invention that extends the five senses by magnifying, by recording, by providing standard units of measurement, and so forth. (p. 6)

International Date Line An imaginary line agreed upon as the starting point for a day on the earth; the 180th meridian. (p. 144)

island arc A chain of volcanic islands, usually curved, that separates a marginal sea from a major ocean. (p. 371, 480)

isobar (Ī′-so-bar) A line that connects points on the earth's surface having the same atmospheric pressure. (p. 259)

kettle lake A lake that formed when a large block of buried glacial ice melted. (p. 464)

lake A body of water that collects in a hole or depression in the earth's surface; larger and deeper than a pond. (p. 340)

landfill A large pit in the ground which is filled with layer upon layer of garbage. (p. 591)

lateral eruption (LAT′-er-ul i-RUP′-shin) An eruption through a weakened side of a volcano. (p. 474)

latitude (LAT′-uh-tood′) The distance that any point is north or south of the equator. (p. 37)

lava (LAH′-vuh) or (LAV′-uh) What magma is called after it reaches the surface of the earth; molten rock on the surface of the earth. (p. 77, 476)

law of gravitation (grav′-uh-TAY′-shin) A scientific law, introduced by Isaac Newton, that states that there is a force of attraction between every object in the universe. (p. 192)

law of inertia (in-ER′-shuh) A scientific law, introduced by Isaac Newton, that states that a body at rest will remain at rest and a body in motion will keep moving in the same direction unless acted upon by some outside force. (p. 193)

leaching (LĒCH′-ing) The removal of minerals in the topsoil layer by water that is filtering down through the soil. (p. 431)

leap year The year in every four years in which an extra day is added to February. (p. 162)

levee (LEV′-ee) A natural embankment formed on both sides of a river by coarser sediments that settle out of flood waters as they first move over the banks of the river. (p. 441)

life form The body form that characterizes a fully grown organism. (p. 559)

lightning A flash of light produced when static electrical charges jump from one part of a cloud to another or from a cloud to the ground. (p. 310)

light year The distance that light travels in one year. (p. 209)

lithosphere (LITH′-uh-sfir) The solid part of the earth that is made up of rock and soil; the earth's crust plus part of the upper mantle; relatively cool and rigid. (p. 16, 504)

living fossils Fossils of organisms that have representatives still living today. (p. 570)

local winds Winds specific to a local area; may blow from any direction. (p. 250)

longitude (LON′-juh-tood′) The distance that any point is east or west of the prime meridian. (p. 37)

low-pressure center The center of an area of low atmospheric pressure; indicated by the letter L or the word Low on a pressure map. (p. 259)

low tide When the waterline of a body of water reaches its lowest point. (p. 409)

low-velocity zone A zone in the earth's upper mantle that has the ability to slow down both P-waves and S-waves. (p. 503)

lunar (LOO′-ner) Having to do with the moon. (p. 171)

lunar eclipse (LOO′-ner ee-KLIPS′) When the earth's shadow falls on the moon's surface, so that that part of the moon cannot be seen from the earth. (p. 178)

luster The way that a mineral reflects the light; can be metallic, glassy, pearly, or dull. (p. 69)

magma (MAG′-muh) Liquid rock melt that is found in some places beneath the earth's surface. (p. 76, 476)

magnetic declination (mag-NET′-ik dek′-luh-NAY′-shun) The difference between true north and magnetic north; also called magnetic variation. (p. 50)

magnetic north The direction toward the North Magnetic Pole from any place on the earth; the direction in which a compass needle points. Compare *true north*. (p. 49)

magnitude (MAG′-nuh-tood′) A classification of a star according to its apparent brightness. (p. 211)

map A representation, on a flat surface, of all or part of the earth's surface. (p. 39)

map projection An attempt to represent the earth's curved surface on a flat surface. (p. 39)

marginal sea A smaller body of salt water found along the margin of a major ocean. (p. 370)

maria (MAHR′-ee-uh) The large, dark, relatively level areas on the moon's surface. (p. 175)

marine climate (muh-REEN′) A climate influenced mainly by maritime air masses; characterized by abundant precipitation; also called an oceanic climate. (p. 317)

maritime air mass (MAR′-uh-tīm′) An air mass that forms over an ocean. (p. 287)

mass The amount of material in something. Mass is the same everywhere and does not vary with gravity. Compare *weight*. (p. 26)

matter Anything that takes up space and has mass. (p. 59)

meanders (mee-AN′-derz) Curves and bends in a stream or river. (p. 442)

mean solar time Time that is based on the average length of a day, from noon to noon. (p. 140)

Mercalli scale (mer-KAL′-ee) A system of twelve steps that are used to describe the amount of damage caused by an earthquake. (p. 497)

meridian (muh-RID′-ee-in) A north-south line that extends between the North and South Poles and that crosses the equator at a right angle. (p. 37)

mesosphere (MES′-uh-sfir) or (MEZ′-uh-sfir) The layer of the earth immediately below the asthenosphere; very hot, and under very high pressure; moderately rigid. (p. 504)

metamorphic rock (met′-uh-MOR′-fik) Rock that is formed when minerals and rocks are changed by very great heat and pressure which changes the crystal structure. (p. 76)

meteorites (MEET′-ee-uh-rīts) Meteors that strike a planet or other object. (p. 181)

meteors (MEET′-ee-uhrs) Particles of stone that travel through space. (p. 181)

meteorology (meet′-ee-uh-ROL′-uh-jee) The science that is concerned with the composition and structure of the earth's atmosphere, and with the many changes that are constantly taking place in the atmosphere. (p. 18)

meter A standard unit for measuring length, based originally on the distance between the North Pole and the equator. (p. 23)

mid-ocean ridge A system of tall, rugged, submerged mountains that extends down the middle of the ocean basins and forms their single most dominant feature. (p. 379, 481)

millibar (MIL′-uh-bar) The unit of atmospheric pressure measurement most commonly found on weather maps. (p. 257)

mine The place that ore comes from. (p. 93)

mineral (MIN′-er-ul) A compound that is found as a natural solid within the earth's crust. All minerals are 1) natural, 2) inorganic, 3) crystalline solids, and 4) made up of key elements. (p. 62)

mineral composition A list of the minerals that make up a rock. (p. 83)

moraine (muh-RAYN′) or (maw-RAYN′) The deposit of material made along its margins by an advancing or retreating glacier. (p. 461)

natural gas A fossil fuel that is a gas rather than a liquid or a solid. (p. 96)

nebula (NEB′-yuh-luh) A huge cloud of matter caused by a supernova. (p. 216)

neutron star (NOO′-tron) An incredibly dense mass of neutrons formed by the inward collapse of matter after a supernova. (p. 217)

nonsilicate minerals (non-SIL′-uh-kit) All the minerals that are not silicates. (p. 66)

noon position The position of the sun when it crosses the north-south line for an observer. (p. 140)

normal fault A fault in which the hanging wall has moved down with respect to the footwall. (p. 491)

North Geographic Pole The point in the Northern Hemisphere where all the meridians, or lines of longitude, meet. Compare *North Magnetic Pole*. (p. 49)

North Magnetic Pole The North Pole that a compass needle points toward; about 1600 km from the North Geographic Pole. (p. 49)

North Pole See *North Magnetic Pole and North Geographic Pole.*

nova (NŌ′-vuh) A temporary flare-up of a white dwarf. (p. 216)

nuclear fusion (NOO′-klee-er FYOO′-zhin) The joining together of lightweight nuclei into a nucleus with greater mass. (p. 186)

observation See *direct observation* and *indirect observation.*

occluded front (uh-KLOO′-did) A weather front that forms when a cold front advances on and lifts a warm front completely off the ground. (p. 293)

ocean (Ō′-shin) The entire body of salt water that covers much of the earth's surface; also, any of its major geographical divisions. (p. 369)

ocean basin The low-lying earth formation that contains the ocean's water; consists mainly of dense basaltic crustal rock. (p. 374)

oceanic crust (ō′-shee-AN′-ik) Crustal rock that is basaltic, denser than granite, and about 5 km thick. (p. 503)

oceanography (ō′-shuh-NOG′-ruh-fee) The science that is concerned with the earth's oceans and their boundaries. (p. 18)

offshore breeze A breeze that blows away from the shore and out over the sea. (p. 255)

onshore breeze A breeze that blows onto the shore from out over the sea. (p. 254)

orbit The path that an object follows as it travels around another object. (p. 148)

ore Any mineral or rock from which a needed substance can be removed cheaply enough and easily enough. (p. 92)

original horizontality See *principal of original horizontality.*

outwash plain A gently sloping area of deposition at the foot of a glacier. (p. 461)

oxbox lake (OKS′-bō) A lake that forms when sediment fills in both ends of a cut-off meander. (p. 442)

oxygen-carbon dioxide cycle (OKS′-uh-jin KAR′-bin dī-OK′-sīd SĪ′-kul) The cycling of oxygen and carbon dioxide that takes place in the atmosphere due to the food-making process of plants (uses carbon dioxide, produces oxygen) and the respiration of animals and the burning of fuels (uses oxygen, produces carbon dioxide). (p. 242)

pack ice Sea ice that has been broken and then refrozen into jagged pressure ridges. (p. 393)

paleontologist (pay′-lee-on-TOL′-uh-jist) A scientist who reconstructs prehistoric life from plant and animal fossils. (p. 560)

parallax (PAR′-uh-laks) The difference in the direction of the line of sight to an object from two different places. (p. 208)

parallax angle The angle that results when an object is viewed from two different locations; it can be used to calculate distances to stars. (p. 208)

parallel (PAR′-uh-lel′) An east-west line or ring that circles the earth parallel to the equator. (p. 37)

penumbra (pi-NUM′-bruh) The lighter part of a shadow. (p. 178)

perigee (PER′-uh-jee′) The point in the moon's elliptical orbit when the moon is closest to the earth. (p. 175)

permeability (per-mee-uh-BIL′-uh-tee) The ease with which water flows through a material. (p. 352)

petrochemicals (pet′-rō-KEM′-uh-kulz) Chemical products made from petroleum. (p. 97)

petroleum (puh-TRŌ′-lee-um) A liquid fossil fuel. (p. 96)

petrology (puh-TROL′-uh-jee) The part of geology that specializes in rocks. (p. 18)

phases of the moon (FAY′-ziz) Recurring changes in the moon's appearance. (p. 176)

photic zone (FŌT′-ik) The uppermost zone of the open ocean; the zone of most light. (p. 396)

photosphere (FŌT′-uh-sfir′) The surface of the sun. (p. 186)

physical property (FIZ′-uh-kul PROP′-er-tee) A feature of a substance itself. Features like color and softness are physical properties. Compare *chemical property*. (p. 9)

physical weathering (FIZ′-uh-kul) A kind of weathering in which a material is changed only in size, becoming smaller as a result of the weathering action. (p. 425)

plastic deformation When rocks bend, flow, and deform like modeling clay, due to stresses and high confining pressures in the earth. (p. 486)

plateau basalts (pla-TŌ′ buh-SAWLTS′) Thick buildups of horizontal layers of basalt on continents that form as a result of lava flows from fissures. (p. 479)

plate tectonic theory (tek-TON′-ik) A theory that views the earth's surface as composed of slowly-moving rigid plates that grow larger, collide, or move past each other with a shearing motion. (p. 508)

polar air mass An air mass that forms near the North or South Pole. (p. 287)

polar climate (PŌ′-ler) A climate influenced mainly by polar air masses; characterized by the coldest temperatures. (p. 316)

Polaris (pō-LAR′-is) The North Star. (p. 123)

pond A body of water that is smaller and shallower than a lake. (p. 342)

pore spaces Open spaces between particles of sand or soil. (p. 352)

porosity (por-OS′-uh-tee) The total volume of the pore spaces in a certain volume of material. (p. 352)

precipitation (pri-sip′-uh-TAY′-shin) Any form of water that falls to the surface of the earth from the atmosphere. (p. 279)

pressure map A map that indicates atmospheric pressure patterns for an area of the earth's surface. (p. 259)

prevailing westerlies Prevailing winds that blow from a westerly direction; the prevailing winds for most of the continental United States. (p. 250)

prevailing winds Winds that are part of much larger patterns of air circulation than local winds; almost always blow from the same direction and travel farther than local winds. (p. 250, 287)

prime meridian (muh-RID′-ee-in) The meridian that passes through Greenwich, England. (p. 37)

principle (PRIN′-suh-pul) An obvious assumption that has become so widely accepted that it is basic to scientific thinking; also called a law. (p. 527)

principle of faunal succession (FAW′-nul suk-SESH′-in) The scientific principle that assumes that the different forms of animals through the earth's past occurred in a definite order or sequence. (p. 532)

principle of original horizontality (uh-RIJ′-uh-nul hor′-uh-zon-TAL′-uh-tee) The scientific principle that assumes that the sediments forming sedimentary rocks were deposited in layers that were parallel to the earth's horizon. (p. 530)

principle of superposition (soo′-per-puh-ZISH′-in) The scientific principle that states that the oldest rock in any undisturbed sequence of rocks is the rock on the bottom. (p. 529)

proper motion The change of the apparent location of a star. (p. 214)

property See *physical property* and *chemical property.*

pulsar (PUL′-sar) A rotating neutron star that gives off pulses of energy (radio waves). (p. 222)

P-Wave A primary wave; a longitudinal earthquake wave. (p. 495)

quarry (KWOR′-ee) or (KWAR′-ee) A strip mine dug to obtain building stone. (p. 587)

quasar (KWAY′-sar) (KWAY′-zar) An object in space that appears to be as large as a very large star but gives off energy comparable to a thousand galaxies. (p. 222)

radial velocity (RAY′-dee-ul vuh-LOS′-uh-tee) The motion of a star in a line toward or away from the earth. (p. 214)

radiation (ray′-dee-AY′-shin) The movement of energy through a material without any aid from the material; also, the movement of energy through empty space. (p. 235)

radioactive decay The changing of a radioactive element into a different element. (p. 547)

radioactivity (ray′-dee-ō-ak-TIV′-uh-tee) The ability of an element to change spontaneously into a different element by losing or gaining matter from the nucleus of an atom. (p. 545)

radiometric dating (ray′-dee-ō-MET′-rik) A method of age determination that measures radioactive decay or radioactive elements. (p. 547)

radio telescope A large saucerlike dish that collects radio waves from space. (p. 219)

rain Drops of water that fall to the earth because they have become too large to remain in the air. (p. 279)

rain gauge (GAYJ) An instrument used to measure the amount of precipitation. (p. 280)

rain-shadow desert A desert caused by a mountain range that prevents prevailing winds from bringing moisture to an area. (p. 324)

recycled (ree-SĪ′-kuld) Changed into a usable form and then used again. (p. 589)

reforestation (ree′-for-ist-AY′-shin) Replanting a forest with new seedlings as trees are removed. (p. 587)

relative humidity A comparison between the amount of moisture in the air and the amount of moisture that the air can hold; expressed as a percentage. (p. 266)

residual soils (ri-ZIJ′-oo-wul) Soils that remain near the bedrock from which they have weathered. (p. 455)

retrograde motions (RET′-ruh-grayd MŌ′-shinz) Apparent reversals in the motions of certain planets. (p. 191)

reverse fault A fault in which the hanging wall has moved up with respect to the footwall. (p. 493)

revolution (rev′-uh-LOO′-shin) The motion of the earth around the sun. (p. 148)

Richter scale (RIK′-ter) A system that measures, on a scale of 1 to 10, the amount of energy released at the focus of an earthquake. (p. 496)

rift valley Deep valley in the center of the mid-ocean ridge; a site of active volcanism. (p. 380)

rift zone The central part of the mid-ocean ridge where molten material rises from the earth's interior and cools into igneous rock. (p. 508)

rigidity (ri-JID′-uh-tee) A measure of the stiffness of a material. (p. 504)

Ring of Fire The region of volcanic activity that surrounds the basin of the Pacific Ocean; same as Circum-Pacific Ring of Fire. (p. 379)

rock A mixture of minerals that is beneath all soil and water on the earth's surface. (p. 76)

rock cycle The process by which rock is changed from one class to another. (p. 82)

rogue wave (RŌG) A very high wave that forms on the open ocean when two or more high waves of about the same wavelengths have their crests coincide. (p. 407)

rotation (rō-TAY′-shin) The daily turning of the earth on its axis. (p. 132)

runoff Water that flows off the earth's surface; can occur as sheet runoff, which is merely across a sloping surface, and stream runoff, which follows a channel. (p. 342)

salinity (suh-LIN′-uh-tee) Saltiness; a measure of the amount of total dissolved materials in water; grams of dissolved materials per kilogram of water. (p. 386)

satellite (SAT′-ul-īt′) An object that revolves around a body larger than itself. (p. 171)

saturated air (SACH′-er-ay′-tid) Air that contains all the moisture it can hold. (p. 266)

saturation temperature (sach′-er-AY′-shin) The temperature at which the air is saturated and can hold no more moisture. (p. 269)

scale of distances A ratio that shows how a distance on a map compares to the actual distance on the earth's surface. (p. 44)

sea floor spreading The faulting and movement of growing plates away from the central rift zone. (p. 508)

sea ice Frozen ocean water. (p. 393)

sedimentary rock (sed′-uh-MEN′-ter-ee) Rock that is formed from sediments. (p. 76)

seismograph (SĪZ′-muh-graf) An instrument that measures and records earthquake waves. (p. 495)

seismologist (sīz-MOL′-uh-jist) A scientist who studies earthquakes. (p. 496)

sexual reproduction Reproduction that involves the joining together of male and female germ cells. (p. 565)

shear stress The stress caused when adjacent materials slide past one another. (p. 491)

sheet runoff Water that has no channels to direct its flow as it runs off the earth's surface. (p. 343)

shield cone A volcanic mountain with gently sloping sides; built almost entirely of lava flow. (p. 477)

SI International System of Units; a system of measuring that uses seven base units and that is based on the metric system. (p. 22)

sidereal month (sī-DIR′-ee-ul) A month that is based upon the moon making one complete revolution; 27⅓ earth days. (p. 177)

silicate minerals (SIL′-uh-kayt′ MIN′-er-ulz) Minerals that contain the elements silicon and oxygen; the most common class of minerals. (p. 64)

sill A layer of igneous rock that is younger than, parallel to, and in between two other rock layers in a formation. (p. 539)

sleet Small pellets of ice that form when raindrops fall through a layer of very cold air and freeze. (p. 280)

sling psychrometer (sī-KROM′-uh-ter) An instrument that measures humidity. (p. 267)

slip face The side of a sand dune that is away from the wind. (p. 460)

snow Precipitation that occurs in the form of flakes when the dew-point temperature and the air temperature are at or below freezing. (p. 279)

solar eclipse (SŌ′-ler ee-KLIPS′) When the moon's shadow falls on the earth's surface, blocking out the sun in that portion of the earth's surface. (p. 178)

solar energy (SŌ′-ler) Energy from the sun. (p. 99)

solar flares Sudden bursts of energy that are given off from sunspots. (p. 187)

solar prominences (PROM′-uh-nun-siz) Cooler gases that appear to leap out of the sun to great heights. (p. 187)

solar system The sun and all the objects that revolve around the sun. (p. 186)

solar wind Streams of electrically charged particles constantly given off from the sun. (p. 189)

solstice (SOL′stis) or (SŌL′-stis) The time of the year when the sun's direct vertical rays reach their farthest point north or south of the equator. (p. 157)

sorting The process by which fragments of earth materials are deposited from running water in order of size, with the largest particles settling first. (p. 454)

specific heat The amount of energy needed to raise 1 g of a substance 1°C. (p. 254)

spectroscope (SPEK′-truh-skōp′) An instrument that analyzes the light given off by stars. (p. 214)

spring The place where ground water flows out of the ground because the water table has intersected the earth's surface. (p. 357)

standard atmospheric pressure Atmospheric pressure at sea level and at 0°C; capable of balancing a column of mercury that is 760 mm (29.92 inches) or 1033.3 cm (33.9 feet) of water; also expressed as 1013.25 millibars. (p. 256)

star traces Curved lines caused by the apparent movement of stars while a time-exposure photo-

graph was being taken; also called star trails. (p. 127)

stationary front A weather front that is not moving. (p. 295)

station model A set of symbols that are used to record conditions at a weather station simply and clearly. (p. 300)

stratified drift (STRAT′-uh-fīd) Sorted particles that have settled out of meltwater on an outwash plain. (p. 463)

stratus clouds (STRAT′-is) Horizontal, layered clouds that stretch out across the sky like a blanket. (p. 277)

streak The color of the powder of a mineral against a white background. (p. 69)

stream Runoff that flows in a channel between banks of soil, rock, or other material. (p. 343)

stream load All the material transported by a river or stream. (p. 439)

strip mine A huge open pit, near the surface of the earth, from which minerals have been removed. (p. 587)

subduction (sub-DUK′-shin) The downward movement of a colliding plate margin that is being forced down toward the asthenosphere. (p. 508)

subsoil The layer of soil that is found under the topsoil of a fully developed soil profile; contains few of the elements needed by plants for growth. (p. 433)

sunspots Dark spots in the photosphere. (p. 186)

supernova The explosion of a supergiant star. (p. 216)

superposition See *principle of superposition.*

surf zone The area near the ocean's margins where breaking waves occur. (p. 406)

swamp A low-lying water-soaked marsh or bog that forms when a lake or pond fills with sediment and vegetation. (p. 342)

S-wave A secondary wave; a transverse earthquake wave; sometimes called a shear wave. (p. 495)

swell A rhythmic pattern of waves of similar wavelength. (p. 406)

syncline (SIN′-klīn) A downward-arching fold in rocks. (p. 486)

synodic month (si-NOD′-ik) A month that is based on the time the moon takes to go from one new moon to the next; 29½ earth days. (p. 177)

tectonics See *theory of plate tectonics.*

temperate climate (TEM′-per-it) A climate influenced by both polar and tropical air masses; characterized by moderate temperatures. (p. 317)

tensional stress (TEN′-shuh-nul) The stress caused when material is pulled apart. (p. 491)

terminal moraine (TER′-muh-nul muh-RAYN′) The deposit that marks the farthest advance of a glacier. (p. 461)

texture (TEKS′-cher) The pattern made by the size, shape, and arrangement of the particles that are in a rock. (p. 83)

theory (THEE′-uh-ree) or (THEER′-ee) A way of explaining how or why something happened, on the basis of generally accepted hypotheses. A working statement that is intended to be tested and modified, added to, or replaced. (p. 14, 59, 535)

theory of continental drift A theory that envisions the continents drifting over the top of the oceanic crust. (p. 505)

theory of plate tectonics (tek-TON′-iks) A theory that views the earth's surface as composed of slowly-moving rigid plates that grow larger, collide, or move past each other with a shearing motion. (p. 508)

thrust fault A special type of reverse fault in which the fault surface is at a very low angle. (p. 493)

thunder A loud rumbling noise caused by the rapid expansion of air as lightning passes through it. (p. 310)

thunderstorm A storm produced by large rising columns of warm moist air and characterized by thunder, lightning, and heavy precipitation. (p. 310)

till The material in a glacial moraine. (p. 463)

time exposure (ik-SPŌ′-zher) A photograph that records the motion of a moving object because the lens of the camera was kept open. (p. 125)

time zone A north-south section of the earth in which all clocks indicate the same time; twenty-four time zones circle the earth. (p. 141)

topographic map (top′-uh-GRAF′-ik) A map that shows the shapes and elevations of the earth's surface features. (p. 45)

topography (tuh-POG′-ruh-fee) The elevations and shapes of land features on the earth's surface. (p. 45)

topsoil The layer of soil that contains humus; found in a fully developed soil profile. (p. 431)

tornado (tor-NAY′-dō) A narrow funnel of air extending down from a cumulonimbus cloud; characterized by high winds traveling in a circular direction around an extremely low pressure center. (p. 311)

transform fault A fault along which there is horizontal movement. (p. 493)

transpiration (tran′-spuh-RAY′-shun) The process by which green plants, as they make food, give off water vapor to the atmosphere through small openings in their leaves. (p. 347)

transported soils Soils formed from eroded materials. (p. 455)

trap A kind of blockage formed by nonporous rock that traps petroleum and natural gas that would otherwise rise all the way to the earth's surface.(p. 97)

trench A long narrow depression of the deep sea floor; generally has steep sides; usually bordered by areas of volcanic activity. (p. 379)

tributaries (TRIB′-yoo-ter′-eez) Streams and small rivers that empty into one large river system. (p. 343)

tropical air mass An air mass that forms near the Tropic of Cancer or the Tropic of Capricorn. (p. 287)

tropical climate (TROP′-uh-kul) A climate influenced mainly by tropical air masses; characterized by the warmest temperatures. (p. 316)

Tropic of Cancer (KAN′-ser) An imaginary line that circles the earth at 23.5° North latitude. (p. 157)

Tropic of Capricorn (KAP′-ruh-korn) An imaginary line that circles the earth at 23.5° South latitude. (p. 156)

troposphere (TROP′-uh-sfir′) or (TRŌ′-puh-sfir′) The layer of the earth's atmosphere that extends from the earth's surface to about 16 km above sea level; the layer of the atmosphere in which all of the earth's weather is found. (p. 257)

trough (TRAWF) The lowest point between two wave crests. (p. 403)

true brightness The amount of light that a star is actually giving off; its luminosity. (p. 211)

true north The direction toward the North Geographic Pole from any place on the earth. Compare *magnetic north*. (p. 49)

tsunami (tsoo-NAH′-mee) A huge wave caused by an underwater earthquake somewhere along the ocean bottom; barely noticeable out at sea. (p. 407)

umbra (UM′-bruh) The dark central part of a shadow. (p. 178)

unconformity (un-kun-FOR′-muh-tee) A surface of erosion between rocks that represents a gap in earth history. (p. 538)

uniformitarianism (yoo′-nuh-for′-muh-TER′-ee-uh-niz′-um) An assumption that the earth processes occurring today are the same as those that have always occurred. (p. 525)

upwelling A process by which deep, cold, nutrient-rich water is brought to the surface and replaces lighter surface water. (p. 414)

valley glacier A glacier that flows down a mountainside. (p. 444)

vent An opening in the earth's crust from which volcanic materials pass to the earth's surface. (p. 475)

viscosity (vis-KOS′-uh-tee) A measure of how easily a liquid flows. (p. 476)

volcanic activity Any earth process by which molten rock, gases, or fragments of solid material come out of an opening (called a vent) in the earth's crust. (p. 475)

volcano A vent or mountain from which volcanic materials pass through the earth's crust to the earth's surface. (p. 476)

volume (VOL′-yum) The amount of space that an object takes up. (p. 28)

warm front A weather front that forms when a warm air mass pushes a cold air mass ahead of it. (p. 291)

water cycle The process by which water is continually recycling between the earth's surface and the atmosphere; also called the hydrologic cycle. (p. 338)

water mass A large volume of water characterized by a similar temperature, salinity, and density throughout its mass. (p. 391)

water pressure The force that a mass of overlying water exerts upon a submerged surface. (p. 394)

watershed All the area of land that drains into a river, along with its system of streams and other tributaries. (p. 345)

water table The boundary between the zone of aeration and the zone of saturation. (p. 355)

water vapor (VAY′-per) The name commonly used for water as gas; cannot be seen, tasted, smelled, or felt. (p. 264)

wave base The point below the surface of water at which the orbital motion of a wave nearly disappears (½ a wavelength below and midheight of the wave. (p. 403)

wave height The vertical distance between a wave's highest and lowest points. (p. 403)

wavelength The horizontal distance from a point on one wave to the corresponding point on the next wave. (p. 233, 403)

weathering (WETH′-er-ing) The breaking down and wearing away of the earth's rocks by the earth's atmosphere; see *chemical weathering* and *physical weathering.* *(p. 425)*

weight The pull of gravity on an object. The weight of the same object can vary depending on gravity. Compare *mass.* (p. 26)

wetlands Coastal and freshwater swamps. (p. 593)

white dwarf A small star that has collapsed inward and is extremely hot. (p. 216)

wind belts General patterns of air circulation that circle the earth; includes prevailing winds. (p. 250)

zenith (ZEE′-nith) The point on the celestial sphere that is directly above the head of an observer. (p. 123)

zone of aeration (ayr-AY′-shin) The layer of soil between the water table and the earth's surface; its pore spaces contain both air and water. (p. 354)

zone of saturation (sach′-er-AY′-shin) The layer of soil below the water table; its pore spaces are filled with water. (p. 355)

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Note: **Boldface** numerals denote definitions.

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